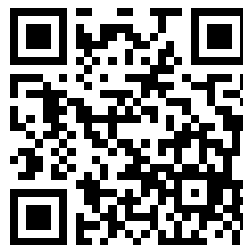

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AIR NAVIGATION



ROYAL AIR FORCE



F O R E W O R D

The R.A.F. Manuals of Air Navigation were withdrawn from public sale at the beginning of the war.

This Manual has been released for publication because it is felt that there is a need for an authoritative book dealing with the principles of air navigation, to be read by the increasing numbers of young air-minded people of the British Isles, and by those members of the general public whose interests lie in aviation and in its future.

The volume is not a reprint of the pre-war publication, but is an entirely new edition written in 1941, and has been revised and amended to include those advances in technique and procedure introduced into Service navigation up to June, 1944.

7th June, 1944.

A.P. 1234

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CALIFORNIA

AIR NAVIGATION

VOLUME I

Published for information and guidance of all concerned

By Command of the Air Council,

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May, 1944



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CHAPTER I

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his vigilance ; unless he practises his art at all times, he will feel at a loss in less favourable circumstances. It is, therefore, essential to make good use of every opportunity given, whether or not the conditions of flight demand the utmost care to be taken in Navigation.

9. Constant practice enables the Air Navigator to recognise without delay the many variable factors affecting the aircraft, and to make the necessary observations and calculations almost automatically. The mental effort, which such reactions on his part entail, become progressively less as his proficiency increases ; but the effort is never entirely absent and the Air Navigator should constantly guard against the inertia induced by flight, especially when things seem to be going according to plan. In fact the successful Air Navigator never stops working, from the moment he is detailed for a flight until the journey is complete.

10. Fortunately the problems presented to the Air Navigator are very stereotyped, and a sound knowledge of the theory of Air Navigation is more than sufficient to cover the requirements of any particular flight. The purpose of the present Manual is primarily to outline the difficulties of flying from one point to another on a spherical World, and to indicate the well-defined categories into which all the problems fall. It will be necessary first to consider some of the general features of the Earth over which the Air Navigator flies, and the means of telling direction, position and distance upon it.

The Form of the Earth

11. In practical Air Navigation and for the purposes of this Manual the Earth is regarded as a sphere, though this does not quite accurately describe its shape. The diameter of a sphere is uniform, but the diameter of the Earth varies a little, that measured between its poles being about 27 statute miles less than the average equatorial diameter which is nearly 7,927 statute miles. This flattening at the poles is called *compression*. The Earth also has a slight bulge in Longitude $08^{\circ} 15'$ West ; so that a section through the Earth at right angles to its axis is not a perfect circle. These irregularities are evidently very slight ; but while generally disregarded by the Air Navigator, they are not inconsiderable to the map-maker, who has to reproduce on paper the physical features of an *ellipsoid*.

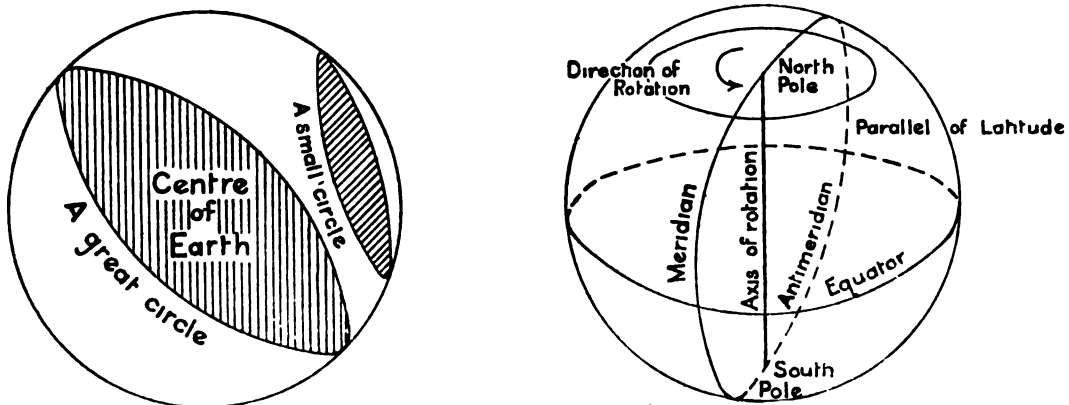


FIGURE 1. Lines on the Earth.

Lines Drawn on the Earth

12. The shortest distance between two points is the length of the straight line joining them. It is, however, impossible to draw a straight line on the spherical surface of the Earth. In other words, all lines drawn on the Earth are curved, some regularly and others irregularly. The following are regularly curved lines imagined to be drawn on the Earth :—

(i) A **GREAT CIRCLE** is a circle on the surface of a sphere whose centre and radius are those of the sphere itself. It follows that the plane of a great circle passes through the centre of the sphere. Only *one* great circle may be drawn through two places on the surface of a sphere that are not diametrically opposite each other. The smaller arc of the great circle joining two places on a sphere measures their shortest distance apart. (See Figure 1.)

(ii) A **SMALL CIRCLE** is a circle on the surface of a sphere whose centre and radius are not those of the sphere. It follows that the plane of a small circle cannot pass through the centre of the sphere. (See Figure 1.)

(iii) **THE EQUATOR** is the great circle whose plane is perpendicular to the axis of rotation of the Earth. It therefore lies in an East-West direction. (See Figure 1.)

(iv) **THE MERIDIANS** are semi-great circles joining the poles, since every such complete great circle forms a meridian and its antimeridian. (See Figure 1.) Every place on the Earth has its appropriate meridian. All meridians indicate the North-South direction.

(v) **PARALLELS OF LATITUDE** are small circles on the Earth whose planes are parallel with the plane of the Equator. They therefore lie in an East-West direction. (See Figure 1.)

(vi) A **RHUMB LINE** is a regular curved line on the surface of the Earth cutting all meridians at the same angle. One such line may be drawn through any two points. The meridians and the Equator are the only examples of rhumb lines that are also great circles. Thus, when two places are not situated on the Equator, or on the same meridian, the distance measured along the rhumb line joining them will not be their shortest distance apart. However, by design, the direction of the rhumb line is constant, and it may therefore be followed often more conveniently between two such places than the great circle joining them, since the direction of the latter changes continuously. (See Figure 2.)

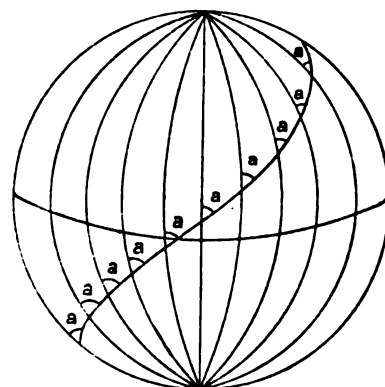


FIGURE 2. A Rhumb Line.

Direction on the Earth

13. The Earth rotates daily about an axis, the extremities of which are *Poles*, quite arbitrarily called *North* and *South*. At any place on the Earth the directions in which the poles lie are named either North or South.

14. The general direction from which heavenly bodies rise is called *East*; and the opposite direction is called *West*. More correctly it should be said that the Earth rotates from West to East. Seen from above the North Pole, the direction of rotation is anti-clockwise, while from above the South Pole it is clockwise.

North, South, East and West are known as *Cardinal Points*. North-East, South-East, South-West and North-West are called *Quadrantal Points*. It should be noticed that the directions North-South and East-West are at right angles to each other.

15. By convention in Air Navigation, directions are measured to the nearest degree, clockwise from North, i.e., from 000° to 360° . They are always expressed as three-figure groups. Thus East, which is 90° from North, is written 090° , and West, 270° .

16. Unfortunately, there are three different Norths from which a direction may be measured, and it is imperative for the Navigator to be able to distinguish clearly between each. So far the only North that has been mentioned is the direction of the North Geographic Pole, called *True North*. The North Magnetic pole is not co-incident with the North Geographic Pole, being situated in North-Eastern Canada at the present time and moving very slowly round the true pole.

17. The direction of the North Magnetic Pole at any place as indicated by a freely-suspended magnetic needle influenced only by the Earth's magnetic field is called *Magnetic North*.

18. If a compass is mounted in an aircraft for the purpose of indicating directions, there may be many metal and electrical components in the aircraft that will disturb the compass needle, causing its North-seeking end to deviate from the direction of Magnetic North. The direction of the North-

seeking end of a particular compass needle is called *Compass North*. Thus the three measurements of the same direction are called :—

True (T), Magnetic (M) and Compass (C).

The full explanation of how these different directions arise is given in Chapter VIII. It will be of assistance, however, at this point to give some consideration to the question.

Variation

19. The angular difference between the direction of True North and Magnetic North, and therefore between all True directions and their corresponding Magnetic directions, is called *Variation*. Variation is measured in degrees and is called Easterly (+) or Westerly (−) according to whether the North-seeking end of a freely-suspended magnetic needle, influenced only by the Earth's magnetic field, lies East or West of True North at any given place. It should be carefully noted that Variation depends upon the location on the Earth, as explained in Chapter VIII. The *sign* given to Variation enables it to be applied directly as a *correction to magnetic directions* to transform them into True directions.

Thus :—	Direction (M)	Variation	Direction (T)
	100° at place A	10° E (+)	110° (See Figure 3(a)).
	100° at place B	10° W (−)	090° (See Figure 3(b)).

A useful rule of thumb is :—

*“ Variation East Magnetic Least
Variation West Magnetic Best.”*

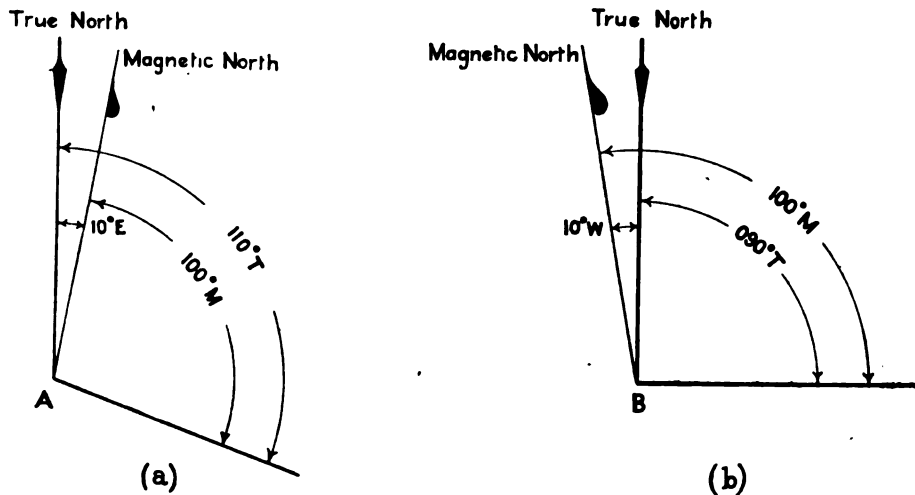


FIGURE 3. Variation.

Isogonals

20. Variation alters from place to place all over the Earth. Lines drawn through places where the Variation is the same are called *isogonals*. These show the Navigator what Variation to apply during any flight. Isogonals at 1° intervals are illustrated in Figure 36, Chapter VIII.

Deviation

21. The angular difference between the direction of Magnetic North and the direction of Compass North, and, therefore, between all Magnetic directions and their corresponding Compass directions is called *Deviation*. Deviation is measured in degrees, and is called East (+) or West (−) according to whether the North-seeking end of a compass needle, under various disturbing influences, points to the East or West of Magnetic North. It should be carefully noted that the value of Deviation varies with the magnetic heading of the aircraft. It also changes from time to time and place to place. This

is carefully explained in Chapter VIII. The *sign* given to Deviation enables it to be applied directly as a *correction to a Compass direction* in order to transform it into a Magnetic direction.

Thus :—	<i>Direction (C)</i>	<i>Deviation</i>	<i>Direction (M)</i>
	100°	4° E (+)	104° (See Figure 4(a)).
	100°	4° W (—)	096° (See Figure 4(b)).

A very useful rule of thumb is :—

*“ Deviation East Compass Least
Deviation West Compass Best.”*

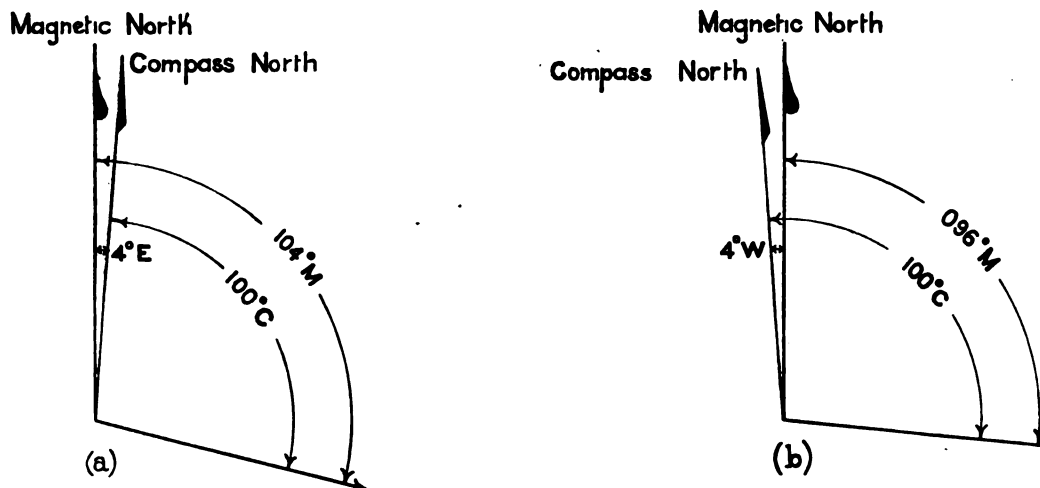


FIGURE 4. Deviation.

22. It should be clear now that a direction given with reference to a particular compass needle may be expressed as a True direction provided the Deviation and Variation are known. The practical value of such a process will be obvious when it is realised that the Air Navigator has continual recourse to a magnetic compass for indications of direction. Yet at the same time, in order to avoid an otherwise hopeless confusion due to the changing values of Variation and Deviation during a flight, all plotting and calculations are invariably in True directions.

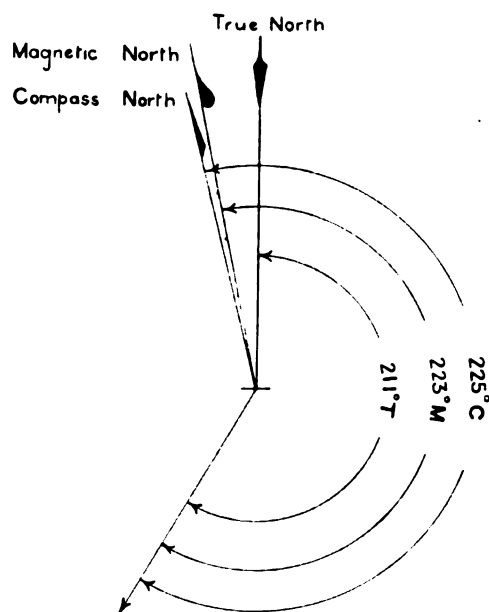


FIGURE 5. Three expressions for the same direction.

23. *Example.*—A direction measured with an aircraft compass is 225°. The appropriate Deviation is — 2° (W), and Variation is 12° W. To what true direction does the compass direction correspond?

Compass direction	225°
Apply Deviation (W) —	2° “ Compass Best.”
∴ Magnetic direction	223°
Apply Variation (W) —	12° “ Magnetic Best.”
∴ True direction	211° (See Figure 5).

Compass Error. (C.E.)

24. *The algebraic sum of Variation and Deviation is called the Compass Error.* This may be applied directly as a correction to Compass directions to obtain True directions.

Thus, if Deviation is $+2^\circ$, and Variation 9° W (—), the C.E. is -7° . A direction of 178° (C) would, therefore, be equivalent to a direction of 171° (T).

It is now possible to examine the various directions that go by special names in Air Navigation.

Course. (Co.)

25. *The direction in which an aircraft is heading is called its Course.* Like all directions, it may be expressed in three ways, namely :—

- (i) True Course, abbreviation : Co.(T) (for Plotting and Calculations).
- (ii) Magnetic Course, abbreviation : Co.(M).
- (iii) Compass Course, abbreviation : Co.(C) (for Steering).

Figure 6 illustrates an aircraft heading in a given direction. This is seen to be a Course of 075° (T), or 065° (M), or 068° (C).

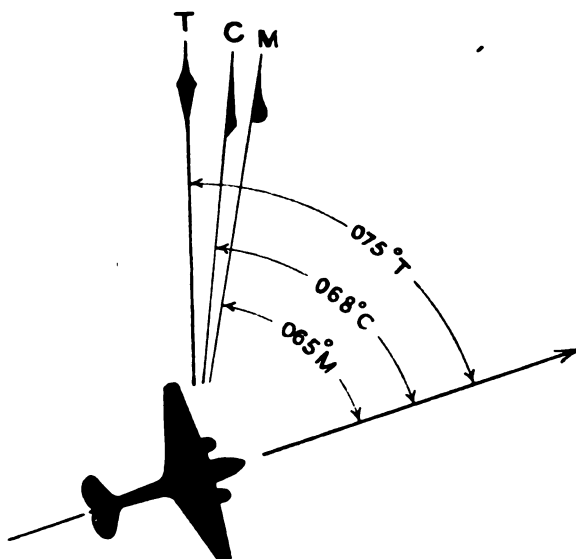


FIGURE 6. Three expressions for Course.

Track. (Tr.)

26. *The direction of the path of an aircraft over the Earth is called its Track.* Again, like all directions, it may be expressed in three ways, namely :—

- (i) True Track, abbreviation : Tr.(T) (always used for Calculations).
- (ii) Magnetic Track, abbreviation : Tr.(M).
- (iii) Compass Track, abbreviation : Tr.(C).

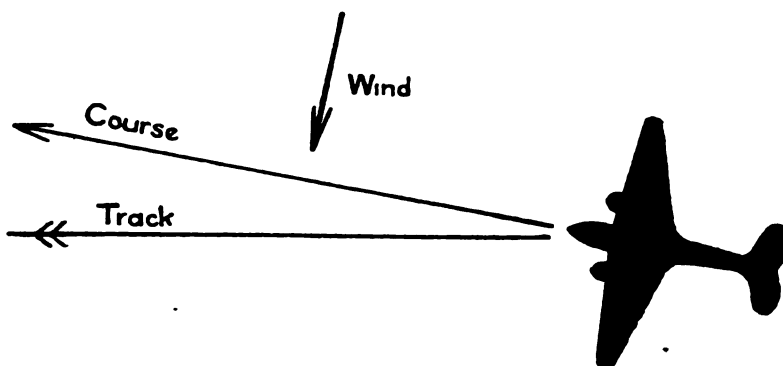


FIGURE 7. The relationship between Course and Track.

The Track will only be the same as the Course when the aircraft is flying in a head wind, a tail wind, or in no wind at all. In all other conditions, the effect of wind will be to make the aircraft pass sideways over the Earth. (See Figure 7.) In this Manual all Tracks are in red.

The path of an aircraft may be along a great circle arc, or along a rhumb line on the surface of the Earth. The former is known as a *Great Circle Track*, and the latter as a *Rhumb Line Track*. A full explanation is given in Chapter III.

The track which an aircraft is supposed to follow is called its *Required Track*.

The track actually traced by the aircraft in flight is called the *Track Made Good* (abbreviation : T.M.G.).

Drift

27. The angular difference between the Course of an aircraft and its Track is called the Drift. Drift is measured in degrees to Port (P) or Starboard (S) from the aircraft's head. Drift is also named + (Starboard) or - (Port) and can then be applied directly to the Course to obtain the Track.

The practical value of a knowledge of drift will become obvious to the student of this manual. Its accurate measurement is of great importance, and the Air Navigator should practice observing drift by whatever means are available in his particular aircraft. It is a common routine among experienced Navigators to "take a drift" at least once every 15 mins., and before and after every alteration of Course, if possible.

Figure 7 illustrates a drift of 10° P.

Bearing

28. The direction of one place from another is called its Bearing. Like all other directions, it may be expressed with reference to three separate Norths, and is accordingly called :—

- (i) A True Bearing.
- (ii) A Magnetic Bearing.
- (iii) A Compass Bearing.

Moreover, the bearing may be along the arc of the great circle between the two places, or along the rhumb line joining them. The former is called a *Great Circle Bearing* and the latter a *Rhumb Line Bearing*.

Back Bearing. (B.B.)

29. The direction observed from an aircraft of a place over which it has previously passed without an intervening alteration of Course is called a Back Bearing.

Here again the Back Bearing may be True, Magnetic or Compass. It should be noted that a Back Bearing is the *reverse direction of the Track* of an aircraft.

Special care is necessary when dealing with Compass Back Bearings, since the Deviation to be applied is *that for the Magnetic Course* of the aircraft while the bearing is taken, and not for the bearing itself. This is fully explained in Chapter VIII.

Thus, an aircraft is flying on a Course of 240° (T) in a locality where Variation is 10° W. Wishing to determine the Track Made Good (T.M.G.), the Navigator takes a Back Bearing by means of a compass and finds it to be 027° (C). The requisite Deviation to be applied to the compass, say $+3^{\circ}$ (E), is that tabulated for a Course of 250° (M), and *NOT* for a Course of 240° (T), or for the bearing of 027° (C). The True T.M.G. is deduced as follows :—

Compass B.B.	027°	
Apply Deviation (E)	$+ 3^{\circ}$	 "Compass Least."
$\therefore$ Magnetic B.B.	030°	
Apply Variation (W)	$- 10^{\circ}$	 "Magnetic Best."
$\therefore$ True B.B.	020°	
Apply $\pm 180^{\circ}$	$\pm 180^{\circ}$	
$\therefore$ True T.M.G.	200°	(See Figure 8).

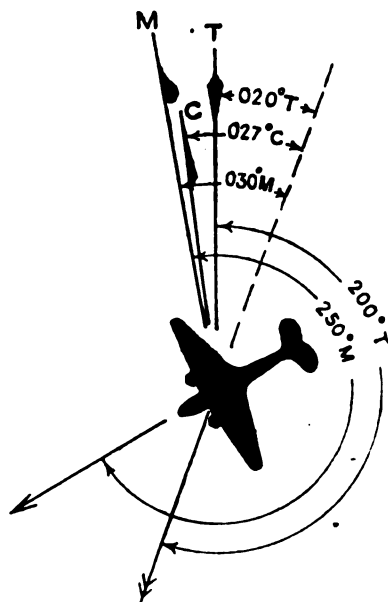


FIGURE 8. The Relationship between Back-Bearing and Track.

Wind Direction

30. The direction FROM which the wind is blowing is called the wind direction.

Unlike other directions it is *always* expressed in True. It is invariably written as a three-figure group. Thus a South wind blows towards the North, and is said to have a direction of 180° , which is understood to mean 180° (T).

Position on the Earth

31. The position of a place on the Earth may be expressed in the four following ways, any of which gives an accurate description for reference purposes :—

- (i) Latitude and Longitude.
- (ii) Lettered Co-ordinates.
- (iii) Military Grid Systems.
- (iv) Place names.

Latitude and Longitude

32. A network of meridians of Longitude and parallels of Latitude is imagined to cover the Earth, and its use as a system of reference for positions on the Earth is universal. This network is called a *graticule*.

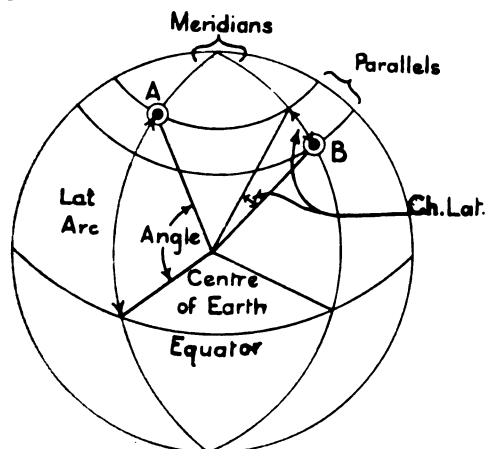


FIGURE 9. Latitude and Change of Latitude.

It is equal to the angle at the centre of the Earth between the radii drawn to the place and to the point where its meridian cuts the Equator. (See Figure 9.)

Change of Latitude. (Ch. Lat.)

35. The change of Latitude between two places (formerly called their difference of Latitude) is the arc of a meridian intercepted between the parallels of Latitude of each place. It is named N or S according to the direction of the change. It is also the angle at the centre of the Earth subtended by the parallels of Latitude of each place. (See Figure 9.)

Longitude

36. Angular Distance along the Equator East or West of the prime meridian is called *Longitude*, E or W, measured in degrees, minutes and seconds from 0° to 180° .

The Longitude of a place is the shorter arc of the Equator intercepted between the prime meridian and the meridian of the place, and is named E or W according to whether the place is East or West of the prime meridian.

It may equally well be expressed as the angle between the planes of the two meridians. (See Figure 10.)

33. In order to complete the system it is necessary to select a certain meridian from which to number the others. This standard meridian is called the *Prime Meridian* and the meridian of Greenwich is generally adopted as the most convenient; but some countries have endeavoured to express individuality by adopting meridians that pass through their respective capitals. The meridians on either side of the prime meridian are termed *East* or *West* according to the side on which they lie.

Latitude

34. Angular distances on meridians are called *Latitudes*, and are usually measured in degrees, minutes and seconds from 0° to 90° from the Equator, though here again a divergent but rare practice exists whereby Latitude is measured from the South Pole, northwards, from 0° to 180° .

The Latitude of a place is the arc of its meridian between the Equator and the place, and is named N or S according to whether the place is North or South of the Equator.

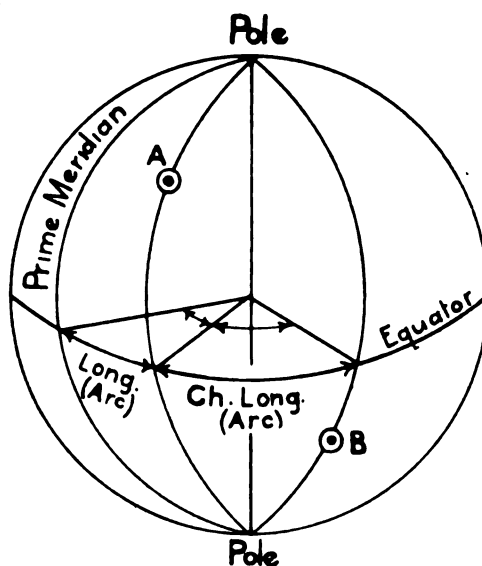


FIGURE 10. Longitude and Change of Longitude.

Change of Longitude. (Ch. Long.)

37. The change of Longitude between two places (formerly called their difference of Longitude) is the *smaller* arc of the Equator intercepted between their respective meridians. It is named E or W according to the direction of the change. It is also the *smaller* angle contained between the planes of the two meridians. (See Figure 10.)

Recording the Position of a Place in Latitude and Longitude

38. By convention, the group of figures expressing Latitude are *always written first*, followed by the figures expressing Longitude. It is not therefore necessary to write the words "Lat." or "Long.", since these are understood. Moreover, all figures below 10 are always preceded by 0, i.e. "5 degrees East" would be written as "05° E." For example, the position of a place situated in Latitude 51 degrees, 21 minutes, 14 seconds North, Longitude 1 degree, 20 minutes, 25 seconds, East, is written

"51° 21' 14" N 01° 20' 25" E", or simply as
"512114 N 012025 E"

The Measurement of Latitude and Longitude

39. The angular units by which Latitude and Longitude are measured are usually *sexagesimal*. That is to say, a right angle is divided into 90 *degrees* (°), each degree containing 60 *minutes* ('), and each minute 60 *seconds* ("). There are unfortunately *centesimal* units of measurement, sometimes used in continental countries. A right angle is divided into 100 *grades* (g), each grade containing 100 *minutes* (') and each minute 100 *seconds* (").

The confusion which such a duplication of units seems to suggest *does not arise in practice* because the sexagesimal units are almost universally used. It is only necessary to explain how to convert centesimal units into sexagesimal units, and vice versa, because isolated occasions might arise when this problem has to be solved, as when recourse is had to some foreign-produced maps.

To Convert Centesimal Units into Sexagesimal Units

40. An angle written in terms of the centesimal unit is expressed as a decimal fraction of a right angle. Multiply the decimal fraction of a right angle by 90, 60 and 60 obtaining after each operation whole number of degrees, minutes and seconds respectively.

Thus 90 g 28[·] 89[^] = 0·902889 right angle
0·902889 right angle (× 90) = 81·26001°
0·26001° (× 60) = 15·6006'
0·6006' (× 60) = 36" (approx.)
Hence 90 g 28[·] 89[^] = 81° 15' 36"

To Convert Sexagesimal Units into Centesimal Units

41. Divide seconds, minutes and degrees in turn by 60, 60 and 90 respectively. The decimal fraction of a right angle is then separated into its component parts.

Convert 81° 15' 36"

36" (÷ 60) = 0·6'
15·6' (÷ 60) = 0·26°
81·26° (÷ 90) = 0·902889 right angle (approx.)
Hence 81° 15' 36" = 90 g 28[·] 89[^]

Longitude may not only be expressed in centesimal units but also referred to an unusual prime meridian.

For example, Barfleur, in France, has a Longitude of 4 g. 04[^] 81[^] W of Paris. It is known that Paris is 2 g. 59[^] 69[^] E of Greenwich. Express the Longitude of Barfleur in sexagesimal measure, referred to Greenwich.

Barfleur is 4 g 04[^] 81[^] W of Paris.
But Paris is 2 g 59[^] 69[^] E of Greenwich.
∴ Barfleur is 1 g 45[^] 12[^] W of Greenwich.
1 g 45[^] 12[^] = ·014512 right angle = 1° 18' 22"

Therefore, Barfleur is 1° 18' 22" W of Greenwich.

Lettered Co-ordinates

42. For the purposes of secrecy, *when reporting positions* by W/T during war, reference should never be made to the actual Latitude and Longitude of a position. The method adopted by all the Services other than the Army and Units of the Tactical Air Force is based on the system already examined.

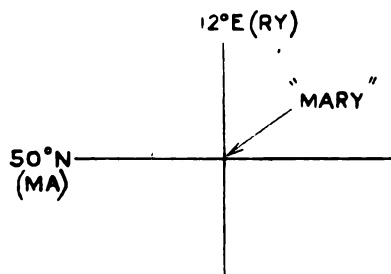


FIGURE 11. Lettered co-ordinates.

43. Each whole degree of Latitude between 70° N and 70° S, and each whole degree of Longitude is allotted a pair of letters that are secretly changed from time to time. The intersection of these lettered co-ordinates may therefore be expressed by a group of four letters and when describing such a point, the letters representing the Latitude co-ordinate are *always named first*.

Thus, in Figure 11, the position
50° N. 12° E. is reported as :—
"MARY"

44. The position of a place is first referred to the nearest intersection of the meridian and parallel of Latitude for whole numbers of degrees, *south-west of the place*, this being a four-letter group. Then the change of Latitude and Longitude between the place and this intersection is expressed in minutes, the minutes of Ch. Lat. *always being given first*.

45. Examples :—

- (i) If 50° N is called DI, and 23° W is called AR, position 50° 15' N, 22° 33' W will be reported as :—
DIAR 1527
- (ii) If 48° N is called CK, and 16° E is called DS, position 48° 35' N, 16° 43' E will be reported as :—
CKDS 3543
- (iii) If 23° S is called RI and 64° E is called ON, position 22° 18' S, 64° 17' E will be reported as :—
RION 4217
- (iv) If 10° S is called CH, and 105° W is called FC, position 09° 52' S, 104° 09' W will be reported as :—
CHFC 0851

It should be noted that the minutes of Latitude and Longitude of the co-ordinates must *always* be given as four-figure groups. Thus, using the letters in example (i), position 50° 00' N 22° 52' W would be written :—

DIAR 0008.

46. The Royal Navy reports position as a bearing (always a three-figure group) and a distance from any intersection of Lettered Co-ordinates. Thus, a position 10 miles due North of intersection DIAR, used in the preceding example, will be reported as :—

000 DIAR 10.

Military Grid Systems

47. These systems are commonly used by the Army to define positions on a map, and are of necessity employed also by the Tactical Air Force, as their work is so closely connected with Army units in the field. The particular system employed is known as the British Modified Grid, which consists of large and small squares overprinted on certain map series.

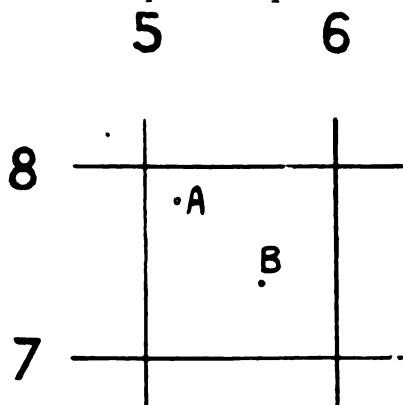


FIGURE 12. Grid Reference.

The largest squares are lettered, and are divided into smaller, lettered squares. (See Figure 13.) These are again divided, and possibly sub-divided (according to the scale of the map) into smaller squares by numbered lines, or "co-ordinates." Each small square is referred to by the numbered horizontal and vertical co-ordinates respectively that form its *South-West corner*.

48. In Figure 12 the square shown would be defined as "57". It cannot be over-emphasised that in all Grid systems, the "longitudinal" co-ordinates are always reported *before* the "latitudinal" co-ordinates. This is in direct contrast with the procedure described for the preceding systems of reference in which the Latitude or its equivalent *invariably* precedes the Longitude or its equivalent. It would be utterly wrong and misleading therefore to report the small square above as "75".

49. Each position can be judged by eye within a small square as so many *tenths* East and so many *tenths* North of the South-West corner. These tenths are appended to the co-ordinate to which they refer. Thus in Figure 12, place A would be reported as " 5278 ", and place B, " 5674 ".

50. As each small square is within a lettered square, itself within a lettered square, the full Grid reference would be preceded by these two letters. However, the letter of the largest square is usually omitted as it may not be known, and anyway it will almost certainly be understood. Only one letter will therefore normally appear in front of the group of figures, namely, that of the smaller lettered square.

51. (i) The complete system of true geometric squares that constitute a Grid can be likened to a square, flat " facet " cut through the surface of the Earth. The side co-ordinate of a selected place called the Origin of the Grid, is aligned with the meridian at that place. To the East and West an angular difference appears between the converging meridians and the rigidly parallel Grid co-ordinates. This angular difference, called " Grid Deviation," sets a limit to the size of any one " facet " because it eventually becomes intolerably great. Any one Grid system cannot therefore be extended indefinitely across the Earth.

(ii) All bearings measured from the co-ordinates are Grid bearings. To obtain True bearings, Grid Deviation must be applied. It is indicated in the margin of the map.

(iii) Figure 13 shows the complete lettered co-ordinates of the British Modified Grid. The subdivision into numbered squares has been illustrated in Figure 12. Examples of grid references are to be found in the margin of all gridded maps.

Place Names

52. Positions on the Earth are most easily reported when flying over fully-developed and well-mapped countries by reference to Place Names. They may seem so obvious as to require no further explanation, yet the following points should be carefully noted by the Air Navigator.

(i) The place named must be prominent and well known, reference never being made to insignificant and unfamiliar natural features, or names.

(ii) The place must not be so extensive as to give rise to ambiguity. For example, an aircraft reported " over London " might be anywhere within an area of about 200 square miles.

(iii) If the aircraft is not actually over the place named, its bearing and distance from that place should be reported. By convention, the bearing is always *of* the aircraft *from* the place and is invariably written to precede the place named. Thus the position of a Navigator who observes DUNGENESS to be due North and distant 5 nautical miles away is reported as:—

180 DUNGENESS 5'

Ground Position (G.P.)

53. *At any time the position on the Earth directly beneath an aircraft is known as its Ground Position.*

A Pin Point is a landmark recognised from the aircraft but which is not necessarily directly underneath the aircraft. A Fix is the ground position of the aircraft, found by direct observation of the ground or by employing wireless or astronomical methods. Since these latter aids are liable to errors, the accuracy of a fix in these instances is limited to the accuracy of the methods used.

Air Position (Air Posn.)

54. *At any time the position of an aircraft whose progress is imagined to have been unaffected by the Wind is called its Air Position.*

This imaginary position is of great practical value, and its plotting on a map or chart is often the first step towards finding either what the effect of the wind has been over a known period of time, or, when the wind effect is known, what the actual position of the aircraft is at that moment.

Every Navigator keeps an accurate record, or log, of the time and position of departure, of the True Courses steered, of the time spent on each Course and of the true airspeeds maintained by the Pilot. From this data the air position can be easily determined at any time on a flight ; and since there can be few doubts attached to any such recorded figures, the air position should be comparatively reliable.

SYSTEM OF LETTERING FOR BRITISH MODIFIED GRID

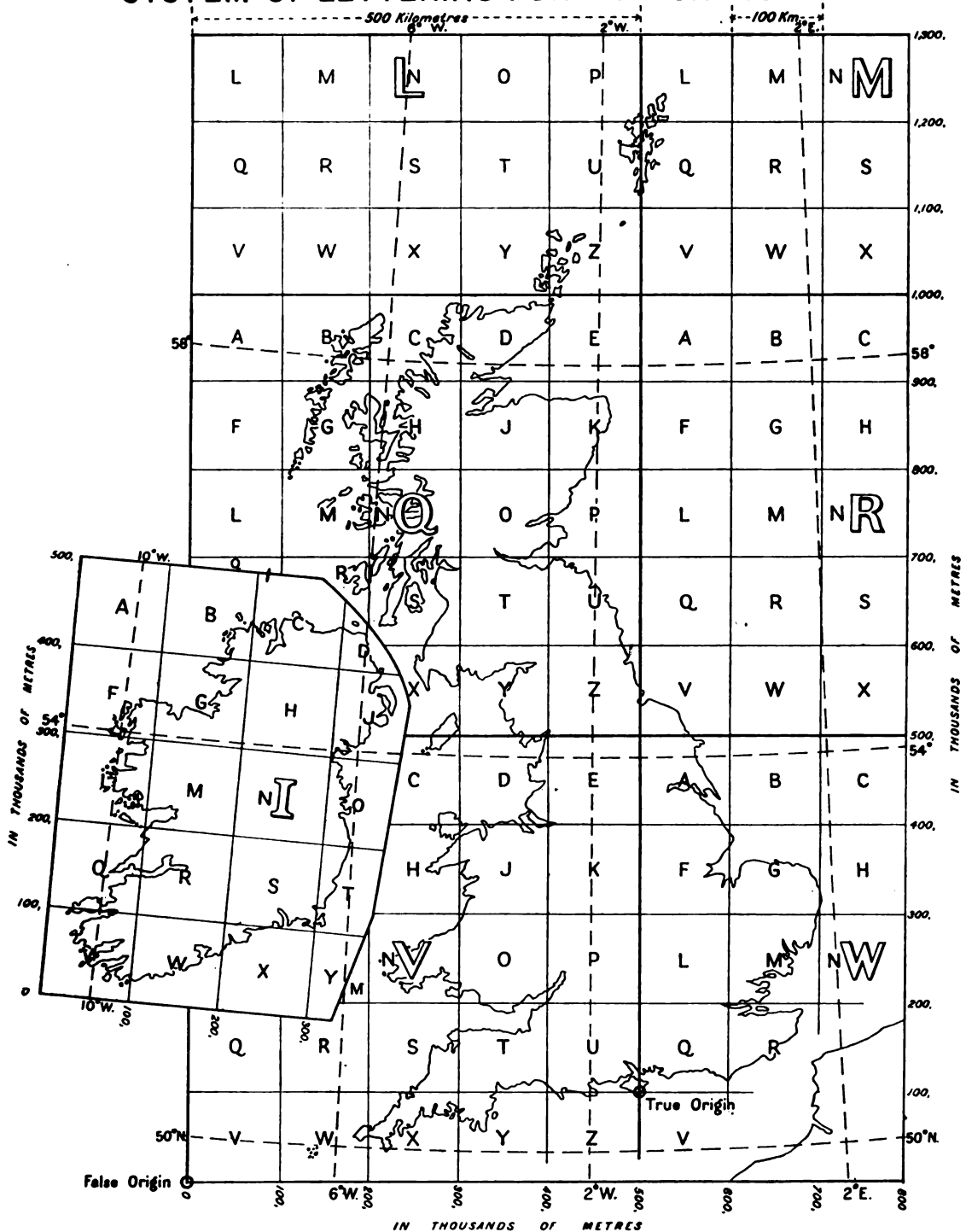


FIGURE 13.

Dead Reckoning Position (D.R. Posn.)

55. *At any time the ground position of an aircraft deduced from a knowledge of the air position and the estimated wind effect is called the Dead (corrupted from "Deduced") Reckoning Position.*

As the wind effect may only be known approximately, and as the process of Dead Reckoning affords opportunities for miscalculation, the D.R. position is never quite free from doubt, the magnitude of which depends upon the time elapsing since a fix was first obtained.

Measurement of Distance

56. The measurement of distance on the surface of the Earth involves the use of units. Unfortunately there are many different units of measurement by which a given distance may be measured ; and even within the United Kingdom the statute mile is not the only linear unit in common use. From the point of view of the Air Navigator the nautical mile is the most convenient and most useful, especially in astro calculations. However, Airspeed Indicators calibrated in both m.p.h. and knots are in use. In future all instruments will be calibrated in knots, and nautical miles only will be used in all calculations.

(i) A Statute Mile (st. m.)

is a length of 5,280 ft., as decreed by a statute of Queen Elizabeth. All maps have a scale of statute miles, but many marine charts have not.

(ii) Nautical Mile (n.m., symbol ')

sometimes called a sea mile, is the average length of one minute of latitude, taken to be 6,080 ft. Because the curvature of the Earth is less pronounced at the Poles than at the Equator, the length of one minute of latitude increases from 6,046 ft. at the Equator to 6,107·8 ft. at the Poles. All maps and charts have a scale of nautical miles. For practical purposes a nautical mile is taken to be the length of 1 minute of arc along *any* great circle on the Earth.

(iii) Kilometre (km.)

is the length of 1/10,000th part of the average distance between the Equator and either Pole. It is equivalent to 3,280 ft. There is a scale of kilometres on most maps but rarely on charts.

Conversion of Units

57. The following approximate values should be known by the Navigator :—

66 n.m.	=	76 st.m. (most important).
41 n.m.	=	76 km.
41 st. m.	=	66 km.
or 5 st. m.	=	8 km.

A useful table of Conversion factors for units of measurement is given in A.P. 1618, *Astronomical Navigation Tables*, Table XII.

Speed and its Measurement

58. *Speed is a rate of change of position.* It is usually expressed as so many units of linear measure per hour ; that is to say, as statute miles per hour (m.p.h.) ; nautical miles per hour, called " knots " (k.) ; or kilometres per hour (km.p.h.).

Airspeed

59. *The speed at which an aircraft passes through the air is called its Airspeed.*

Airspeed Indicators on British aircraft are calibrated in either m.p.h. or knots, and the Navigator should ascertain the unit of speed of any particular instrument used : it is marked on the dial.

The Airspeed Indicator by which this speed is measured is fully explained in A.P. 1275B. It is operated by the pressure set up inside a tube exposed to the air flow past the aircraft, and fed to a sensitive diaphragm. The instrument suffers from three defects :—

(i) The instrument may suffer from constructional defects that cause *Instrument Error*, which can, however, be calibrated.

(ii) The tube may be affected by air eddies set up round the aircraft. This gives rise to what is known as *Position Error*, which can be tabulated for each type of aircraft.

(iii) The instrument is calibrated on the assumption that the air density is that which occurs with an air pressure of 1013 mb. and temperature of 15° C. ("zero height" in the I.C.A.N. atmosphere). Since air density decreases with height, the airspeed indicator reads too low at great heights. A reasonably accurate correction is made by using the Navigational Computer, Mk. III, on which the indicated airspeed, external air temperature and indicated height are set. Roughly, at about 10,000 ft. the T.A.S. is about 15 per cent. in excess of the R.A.S., and at 20,000 ft. it is about 40 per cent. in excess of the R.A.S.

The Derivation of True Airspeed

60. All navigational calculations are naturally concerned with True Airspeeds. To accept the reading of any particular instrument at its face value is asking for trouble, because satisfactory true-reading airspeed indicators have not yet been developed. This True Airspeed can only be obtained by applying corrections to the instrument reading. Some of these corrections can be effected by means of a special instrument called an Airspeed Computer, which is mounted on the back of a Navigation Computer, Mk. III (see Chapter XII, para. 81), or made separately (see A.P. 1275B). The True Airspeed is derived as follows:—

- (i) Indicated Airspeed (I.A.S.). This is the reading of a particular instrument uncorrected for errors.
- (ii) Rectified Airspeed (R.A.S.). The Indicated Airspeed corrected for instrument and position errors.
- (iii) True Airspeed (T.A.S.). This is the Rectified Airspeed computed for height and temperature. When computing the True Airspeed the normal procedure is to use the Indicated Height and the outside temperature shown by the air temperature gauge.

Airspeed Indicators—Recording of Corrections

61. There are two Corrections to be considered in the preparation of Correction Cards for Airspeed Indicators. The first is *Instrument* error, and the second *Pressure Head Position* error.

Instrument error is a mechanical error due to the incorrect construction of the working parts of the instrument, and the error in scale calibration of the dial. It can be determined by checking against an Airspeed Indicator Calibrator, Mk. IV. and IVE or IVF (6C/85 and 151 or 222).

Position error is caused by the uneven air flow over the outline of the aircraft in the vicinity of the Pressure Head. It varies for different speeds of the aircraft, but the Table of Errors is generally constant for any one type of aircraft; though, in certain instances, major modifications to the airframe do make a difference. (This error is ascertained in the development stages of the manufacture of the aircraft.)

Position errors are recorded against corresponding Indicated Airspeeds. It must be emphasised that this means Indicated Airspeed with Corrections to counter instrumental error applied.

Preparation of Airspeed Indicator Correction Cards

(i) Measure the Instrument error of the individual Indicator. The Instrument Error Correction is obtained by subtracting the Instrument reading from the Calibrator reading.

(ii) Consult the "Position Error" Table (P.E.), as given in the A.P., Vol. 1, of the aircraft. The well-established term "Position Error" means the Corrections necessary to counter Position Error. In the Tables, the errors are shown as additions or subtractions of multiples of two miles per hour between varying speeds. For example, if, from 100 to 140 m.p.h., the P.E. is + 4, and, from 140 to 160 m.p.h., the P.E. is + 2, the mean Indicated Airspeed value at 120 m.p.h. will be + 4, and at 150 m.p.h., + 2. The values of P.E. between these speeds will then be recorded mathematically (i.e., at 130 m.p.h. the P.E. = 3·4, at 140 m.p.h. the P.E. = 2·7).

(iii) Construct a table to find the necessary Total Corrections. The Total Correction is the algebraic sum of the Instrument Error and Position-Error.

(iv) Prepare a graph, plotting the Total Corrections against the Instrument Readings.

(v) Make out the "Critical Table" on R.A.F. F.1167 or 1167A.

An example of the Table is as follows :—

Calibrator Reading.	I.A.S.	I.E. Correction.	P.E. Correction.	Total Correction to I.A.S.
140	139	+1	+1	+2
150	150	0	0	0
160	160	0	-0.7	-0.7
170	171	-1	-1.4	-2.4
180	181	-1	-2.5	-3.5
190	192	-2	-3.5	-5.5
200	202	-2	-4.5	-6.5
210	213	-3	-5.5	-8.5

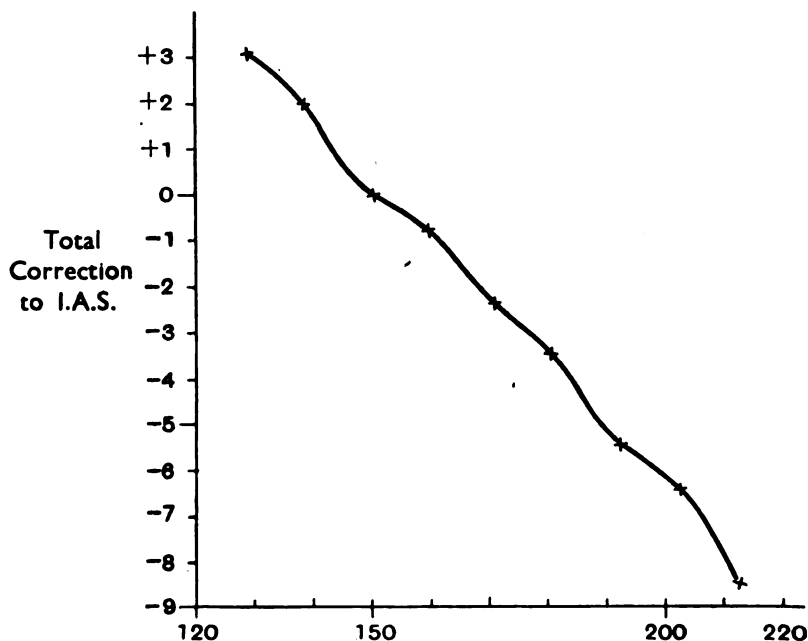
I.A.S.

Construct a graph, plotting Total Correction against Indicated Airspeed. Mark off half values of Total Correction, and so determine the critical points at which Total Corrections change by a whole number.

The Critical Table is then entered on F.1167, suitably amended, as shown below :—

R.A.F. FORM 1167

I.A.S.	Correction to obtain R.A.S.
124	
134	+3
141	+2
147	+1
157	0
165	-1
172	-2
181	-3
187	-4
193	-5
202	-6
208	-7
213	-8



Ground Speed. (G/S)

62. The speed at which an aircraft travels over the ground is called its Ground Speed.

In practice the Air Navigator is much concerned with the determination of ground speed, and students of this Manual will soon realise the importance of its measurement. It may be found in three principal ways :—

- (i) By measuring the distance between two places on the Earth over which the aircraft is observed to pass in a known time.

(ii) By measuring the time taken by the aircraft to cover a chosen distance on the ground. This is effected by means of various instruments that take into account the height of the aircraft above the ground. (The Course Setting Bomb Sight and the Drift Recorder, Mk. II.) A completely satisfactory direct-reading Ground Speed Indicator has yet to be developed.

(iii) By calculating the effect of the wind on the progress of the aircraft. This method is explained in detail in Chapter V.

It is immaterial whether the ground speed is measured in m.p.h. or knots, though it is customary to adopt the units in which the Airspeed Indicator happens to be calibrated. Many Navigators prefer to use knots at all times, since the nautical mile is more convenient than the statute mile as a unit of distance when employing astronomical methods of Navigation.

Wind Speed. (W/S)

63. As a general rule the Wind speed given by Meteorologists is in m.p.h. unless specifically asked for in other units. The Air Navigator may, however, measure the Wind Speed in whatever unit is most convenient to him.

Height. (Ht.)

64. The height of an aircraft is subject to almost as many qualifications as its airspeed. The height *above mean sea level* and the height *above the ground* are obviously two very different things, yet both are in common use by the Navigator according to circumstances. For example, when considering aircraft performance, such as heights for economical cruising, or the computation of True Airspeed, height above mean sea level is the deciding factor. On the other hand, when measuring ground speed by observing the passage of objects through an instrument like the Drift Recorder, Mk. II, or when flying in mountainous regions, or making a blind approach to an aerodrome, or when setting up a Bomb Sight, it is the height above the ground that matters.

65. Heights are registered approximately by the altimeter, which is an aneroid barometer calibrated in terms of height in feet instead of in units of pressure. This is possible because pressure decreases with height.

There are two main types of altimeter, according to whether the relation between pressure and height used in calibration is based on the assumption (a) that the temperature of the atmosphere is 50° F., Isothermal calibration, or (b) that it follows the I.C.A.N. law. Altimeters calibrated according to the latter law are now used on all aircraft except elementary training types, as they give a decidedly better approximation to average conditions. For further details of the calibration of altimeters, see A.P. 1931 (Meteorological Handbook for Pilots and Navigators).

The Mark XIV altimeter, now in general use on operational aircraft, reads height above the level of the pressure shown on the pressure sub-scale. If, before take off, the altimeter is set so that the height needles read the height of the aerodrome above mean sea level, the sub-scale will read approximately the value of pressure at mean sea level, and the altimeter in flight will read approximately the value of pressure at mean sea level, and the altimeter in flight will read approximately height above mean sea level.

The readings of the altimeter need correction on account of (a) deviation of mean sea level pressure from the setting value, and (b) deviation of air temperature from that assumed in the calibration law.

The first correction is much the more important. It is allowed for by the changing the setting of the altimeter as the aircraft flies over areas of changing mean sea level pressure by turning the setting knob so that the new value of mean sea level pressure is shown on the sub-scale. Values of mean sea level pressure (QFF), to enable this to be done are given on the weather forecast. An altimeter uncorrected for changing mean sea level pressure can easily be incorrect by 800 feet after a flight of 400 miles. It should be remembered that when flying into an area of low mean sea level pressure (depression, trough) the altimeter will, unless corrected, read too high, while flying into an area of high pressure it will read too low.

The correction for temperature deviation from the standard will very rarely be as much as 10 per cent. of the indicated height. The rule for the sign of the correction is that in very cold weather (i.e.

cold for the height, -25°C . is normal, but -40°C . would be cold, at 20,000 feet), the altimeter reads too high and in warm weather reads too low. This error can be approximately allowed for by using the Mark IIID navigational computer which, from a reading of the outside air temperature shown on the aircraft's thermometer, gives a good correction to the indicated height.

For landing in conditions of poor visibility and especially when using beam approach, it is necessary for the altimeter to read height above the aerodrome level. This is ensured by obtaining by wireless from the aerodrome the value of aerodrome level pressure (QFE). The altimeter is set so that this pressure is shown on the sub-scale and it will then read height above the aerodrome. Values of QFE are given in the weather forecast on Form 2330 for the aerodrome of destination or likely diversion aerodromes, but the predicted value should be used only when a value of QFE cannot be obtained by wireless as the aerodrome is approached.

Calibration of Altimeters

66. Altimeters suffer from mechanical defects which should be tested from time to time by calibration, as described in A.P. 1275B. A quick test of the sensitive Altimeter should be made before starting every flight, as follows :

(i) Obtain from the Meteorological Officer the atmospheric pressure at the aerodrome level and set this on the sensitive Altimeter pressure-dial.

(ii) The Altimeter should read zero height. If it does not, it is obvious whether the Altimeter is reading High or Low, and if so by how much, in feet.

67. An Altimeter registers the height that corresponds to the surrounding atmospheric pressure. The pressure inside an aircraft differs considerably from the atmospheric pressure surrounding the aircraft and consequently the Altimeter has to be connected to the static side of the *Pressure Head*, as this closely approximates to the true outside atmospheric pressure. Even this is, however, not perfectly representative, and hence at any one level an Altimeter will register a height varying with the Indicated Airspeed and the type of aircraft. The error in height shown is akin to the *Position Error* of an Airspeed Indicator, and can be similarly treated as a correction to apply to Altimeter readings to obtain true heights. In particular, a correction must be applied to the aerodrome level atmospheric pressure (QFE*) for setting on the Altimeter when making a blind approach.

68. Instruments for registering height above the ground are still at the development stage. At present the most practical method of finding height above the ground is to determine the True Height above sea level (by computing from the Indicated Height) and then to subtract the height of the ground above sea level (as recorded on a topographical map).

69. *Example* :—

Indicated Height	10,000 ft. (I.C.A.N.).
Altimeter reads	30 ft. too high.
∴ Corrected Indicated Height	9,970 ft.
Air temperature	-15°C .
∴ True Height	9,570 ft.
Height of Ground	540 ft.
∴ Height above Ground	9,030 ft.

* See Chapter XI, paragraph 13.

CHAPTER II

MATHEMATICS

"Can you do addition?" the White Queen asked. "What's one and one and one and one and one and one and one and one and one and one?"

—ALICE THROUGH THE LOOKING GLASS.

Importance to the Air Navigator

1. The processes of calculation used by the Air Navigator are basically Arithmetical and Geometrical. This does not mean to say that the Navigator must be experienced in the realms of higher mathematics in order to do his job satisfactorily, but it does mean that inability to grasp elementary mathematical processes will be a very serious handicap. The beginner, or for that matter any Air Navigator who is out of practice, would do well to exercise his mind on simple arithmetic. He will thereby prepare his faculties for rapid and effortless solution of the very easy mathematical problems which are the everyday experience of the practical Navigator. The ability to think clearly is always impaired during flight on account of the vibration, noise, cold, distractions and reduced oxygen, to say nothing of nervous strain either conscious or unconscious. It follows that in the extreme case the Navigator will fail to realise that two and two make four. Addition, subtraction, multiplication and division form the back-bone of navigational calculations, and it is the mind which is well-practised in quick thinking that makes fewest mistakes in the air, particularly if it has kept a pace or two ahead of the easy problems met with in flight.

2. The present Chapter is not intended to provide exercises of this kind. Any elementary textbook is suitable. What follows here is only a guide to the rest of this volume, and Air Navigators wishing to pursue their subject further than is strictly necessary in practice must be prepared for a certain amount of higher mathematics.

Velocity

A velocity is a rate of change of position in a given direction.

3. A velocity is comprised of both speed and direction. The statement that an aircraft has a velocity of 300 m.p.h. is incomplete without an indication of the direction of flight. If, however, an aircraft is said to be travelling at 300 m.p.h. in a direction of 145° T, its velocity has been completely described. So long as the speed and direction both remain unchanged, the velocity remains constant; but as soon as either speed or direction, or both, are changed, the velocity has changed too. Therefore the aircraft whose original velocity was 300 m.p.h. in a direction of 145° T, assumes another velocity if Course is altered, say, to 180° T.

A Vector

A vector is a graphical representation of a velocity.

4. Since a velocity implies a speed in one direction, it may, for convenience, be represented graphically by a straight line whose length is determined by an arbitrary scale, and whose direction is referred to an arbitrary datum line. The scale adopted is one that happens to be the most convenient for any particular purpose; but the datum line is by convention always drawn from top to bottom of the page, the direction of True North being at the top and South at the bottom. In order to make the direction and scale of a vector quite clear it is usual to draw the datum line to which all directions are referred, if no obvious datum line exists; the scale is indicated either by a statement in words as for example,

1 inch = 30 knots,

or by drawing a scale line from which the speeds are measured.

For example, if an aircraft has a velocity of 280 k in a direction of 315° T, this may be represented vectorially by AB in Figure 1. Since there is no obvious datum line, it is necessary to show a meridian as illustrated. The scale adopted is indicated underneath.

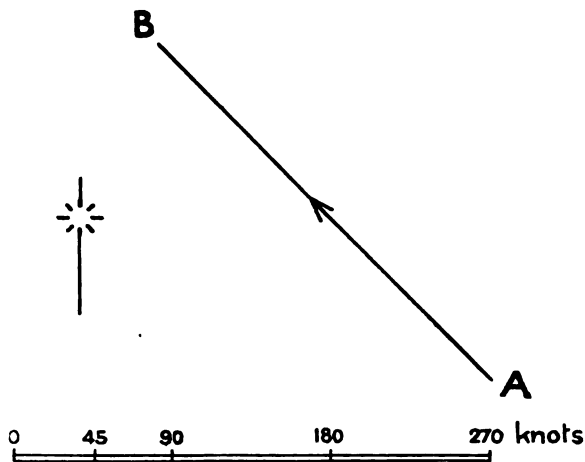


FIGURE 1. A Vector.

Acceleration

Acceleration is a rate of change of velocity.

5. It should be understood from the description of a velocity that an acceleration may be caused not only by a change in speed, but also by a change in the direction of motion, whether or not the speed remains the same. For example, when an aircraft flying at 260 m.p.h. in a direction of 035° T alters Course to 080° T, it undergoes an acceleration at the moment of turning. Consequently, an aircraft executing a constant turn at a fixed airspeed and rate of turn may be said to experience a constant acceleration since the direction of its motion changes continuously. More obvious cases of acceleration occur when an aircraft climbs, glides or changes speed in flight; but many uncontrollable accelerations are also experienced due to bumpy air conditions or the surging progress of the aircraft.

Accelerations give rise to the eccentric behaviour of aircraft compasses, and create difficulties when observing altitudes of celestial bodies by means of bubble sextants.

6. The Arrow Convention.—In order to simplify the graphical solution of velocity problems a convention has been adopted with regard to the labelling of vectors :—

- (i) Vectors of Courses are marked with a single arrow, indicating the direction in which the velocity operates, thus :—



- (ii) Vectors of all Tracks are marked with a double arrow, indicating the direction in which the velocity operates, thus :—



- (iii) Vectors of all Wind Velocities are marked with a triple arrow, indicating the direction in which the velocity operates, thus :—



- (iv) Vectors of all Relative Velocities are marked with a cross (two single arrows end on) together with an arrow indicating the direction in which the navigator's aircraft is opening or closing, thus :—

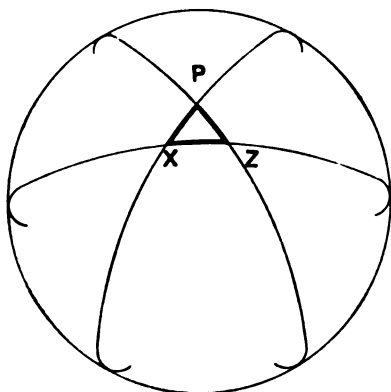


FIGURE 2. A Spherical Triangle.

In order to clarify the meaning of a vector beyond all doubt in the early stages of training, it should be clearly labelled "Course and True Airspeed," "Track and Ground Speed," "Wind Velocity," "Ship's Track and Ground Speed," and so on, as applicable. In this manual, for the sole purpose of clarity, all tracks are shown in red.

Spherical Triangles

7. Triangles on a sphere whose sides are arcs of great circles are called spherical triangles. The length of each side is measured in degrees, minutes, and seconds of arc. Moreover, the angles contained between the sides are the same as the angles contained between the planes of the great circles, and are also expressed in degrees, minutes and seconds. Figure 2 illustrates a typical spherical triangle.

8. Spherical triangles may be solved in much the same way as plane triangles. When using astronomical observations the Air Navigator, in practice, is relieved of all onerous calculations by being provided with the tabulated dimensions of a large variety of spherical triangles, published in A.P. 1618, *Astronomical Navigation Tables*.

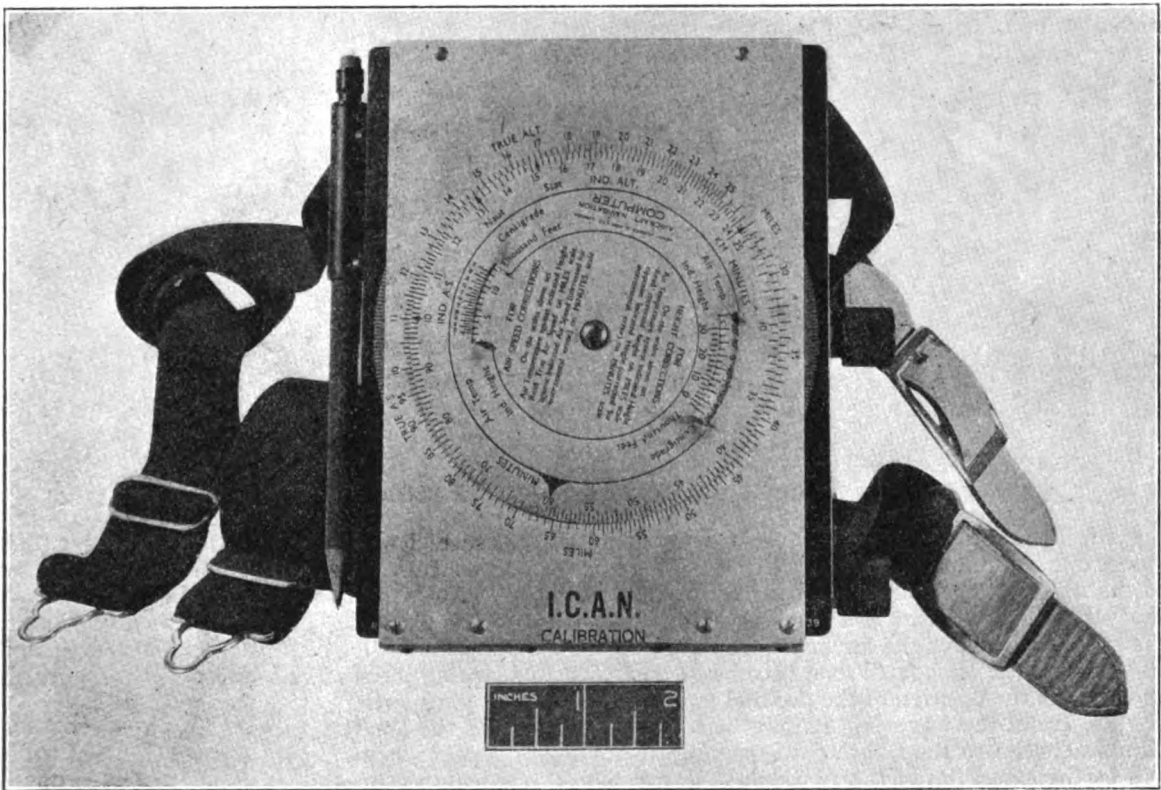


FIGURE 3. The Circular Slide Rule on the Navigator Computer, Mk. III.

Slide Rules

9. The Navigator should avoid as much mental calculation in the air as possible, committing all possible figures to paper, and solving as many problems as possible mechanically. One of the most useful aids to rapid calculation is supplied by the slide rule. The Navigator who is adept in its use saves himself a great deal of mental exertion and time. The ordinary straight slide rule has been adapted for the use of Navigators in a circular form, mounted on the Navigation Computer, Mk. III (see Figure 3). The use of either the straight or circular slide rule is identical, except that the latter consists of only two scales instead of the usual four, and therefore cannot be used as quickly as the former for complicated problems. However, the type of problem met by the Navigator in the air is always capable of rapid solution by means of the circular slide rule.

Principle of the Rule

10. Logarithms are used to facilitate the arithmetical processes of multiplication, division and evaluation of numbers raised or reduced to given powers. By adding together the logarithms of various numbers, the logarithm of their product is obtained. Similarly, the division of numbers is achieved by the subtraction of the logarithm of the divisor from the logarithm of the dividend. That is to say,

$$\log (a \times b) = \log a + \log b,$$

$$\log \left(\frac{a}{b} \right) = \log a - \log b.$$

It may also be stated that :—

$$\log (a^4) = 4 \log a,$$

$$\log \left(\sqrt[3]{a} \right) = \frac{1}{3} \log a.$$

11. The logarithm of a number consists of two parts. First, the figure in front of the decimal point, called the "*characteristic*": and secondly, the figures after the decimal point, known as the "*mantissa*." When obtaining the logarithm of a number, its *characteristic* is dependent upon the position of the decimal point; but the *mantissa* depends on the group of figures that comprise the number.

12. For example, in Inman's Tables, the log of 2865 is given as .45712. This is the *mantissa* for such a group of figures, and it should be known that

$$\begin{aligned}\log 2865 &= 3.45712 \\ \log 286.5 &= 2.45712 \\ \log 2.865 &= 0.45712, \text{ and so on.}\end{aligned}$$

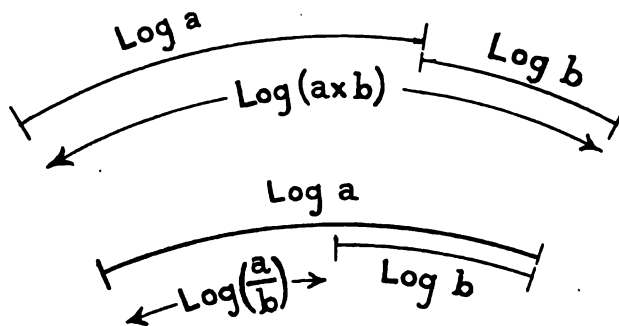


FIGURE 4. The Principle of a Circular Slide Rule.

13. The simplest slide rule consists of two identical scales which are constructed from the logarithmic values of natural numbers. That is to say, the spacing between consecutive natural numbers corresponds to the difference between the *mantissae* of those numbers. An inspection of a circular slide rule will show that there appears to be no beginning and no end to these scales. This is explained by the fact that the *mantissa* for the log of 1 is the same as the *mantissa* for the log of 10, 1000, 100,000 or .00001, and so on. The Navigator soon becomes accustomed to adapting the scales for any particular problem, and decides the position of the decimal point in the answer by inspection. (See paragraph 16.)

14. From the foregoing, it may be seen that by placing the length corresponding to the log of a number end on to the length corresponding to the log of another, as in Figure 4, the combined length will be the logarithm of their product. Conversely, if one length is subtracted from the other, the log of their division is obtained, as in Figure 4.

Use of the Circular Slide Rule

15. It will be found convenient to have a circular slide rule at hand when reading these paragraphs.

(i) Multiplication

Example :—

Suppose an aircraft travelling at a ground speed of 258 knots continues at this speed for 11 hours 15 minutes. How far will the aircraft have travelled?

*Answer :—*The problem to solve is : 258×11.25 n.m.

On the outer scale mark with a pencil the point corresponding to the numbers 258 which occur between 25 and 26. Now turn the inner scale until this mark is opposite 10 on the inner scale, and against the numbers 1125 on the inner scale, read the answer on the outer scale. This is found to be 2900 n.m. The position of the decimal point is decided by inspection, as explained in paragraph 16.

(ii) Division

Example :—

Suppose an aircraft is flying at 315 k. How far will it travel in 1 minute?

*Answer :—*The problem to solve is : $315 \div 60$ n.m.

Mark on the outer scale the point at which the figures 315 occur, that is, 31.5. Now turn this point until it coincides with 60 on the inner scale, and against 10 on the inner scale read the answer on the outer scale, namely 5.25 n.m. Here again the position of the decimal point is a matter of inspection as explained later.

(iii) Simple Proportion (Rule of Three)

This is very easily solved by the slide rule.

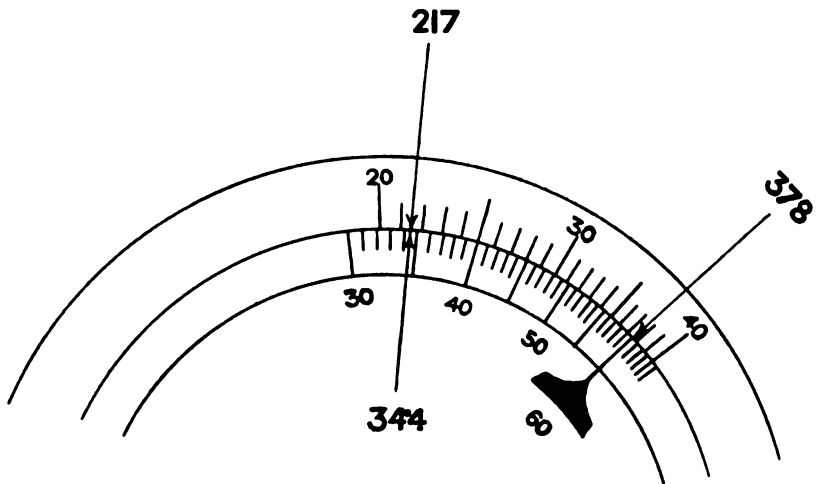


FIGURE 5. Simple Proportion by Slide Rule.

Example :—

An aircraft flying at 378 k is travelling from A to B, a distance 217 n.m. How long will the journey take ?

*Answer :—*The problem to solve is : 60 minutes : 378 n.m. :: x minutes : 217 n.m.

Set the mark at which the figures 378 occur on the outer scale against 60 (marked distinctly) and against the figures 217 on the outer scale, read the answer on the inner scale, namely 34 minutes (approx.). (See Figure 5.)

Again, it has been seen that the ratio between statute miles and nautical miles is 76 : 66. (Chapter I, paragraph 57.) By setting these numbers on the scales opposite each other, a reading on the one scale will have its equivalent value on the other.

Example :—

How many statute miles are equivalent to 460 nautical miles ?

*Answer :—*The problem to solve is : 66 : 76 :: 460 : x .

Set 76 on the outer scale against 66 on the inner scale. Then against 460 on the inner scale the answer is read on the outer scale, namely 530 st. m.

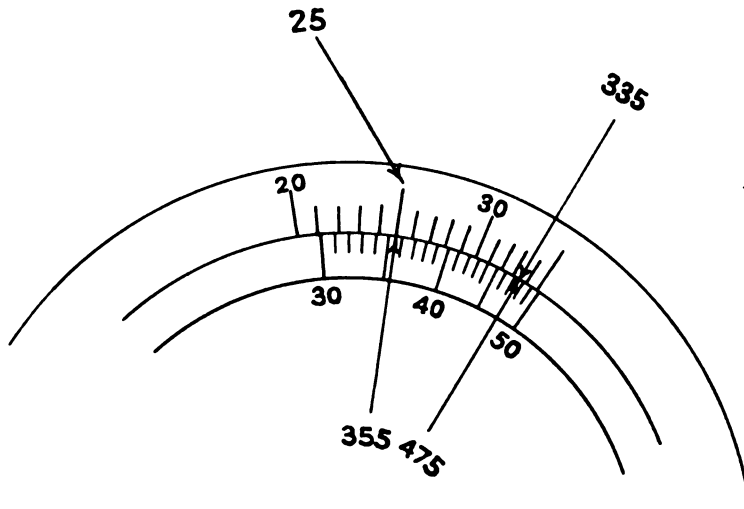


FIGURE 6. Compound Fractions by Slide Rule.

(iv) Compound Fractions

The rule to remember when solving all compound fractions is :

First divide, then multiply, taking each factor in turn.

In this way the number of operations are greatly reduced, though the answer will be the same whatever order is used in solving the fraction.

Example :—Evaluate $\frac{250 \times 4750}{3 \cdot 55}$ (See Figure 6.)

Answer :—Set 25 on the outer scale against 355 on the inner scale, and read the answer on the outer scale against 475 on the inner scale, namely, 335,000 approx. The number of figures in front of the decimal is decided by inspection. (See paragraph 16.)

It should be noted that the absence of the *Cursor* or sliding index from the circular slide rule may be overcome by the use of a lead pencil to mark either scale as required.

Example :—Evaluate $\frac{2 \times 3 \times 4}{5 \times 7 \times 9}$

Answer :—First divide 2 by 5, and without altering the setting, multiply by 3, marking the result by pencil ; repeat the process by dividing the result first obtained by 7, and multiply by 4, marking the result with a pencil ; finally divide by 9, and read the answer, namely 0·0762.

The Decimal Point

16. While using a slide rule, *never worry about the position of the decimal point until the group of figures comprising the answer has been obtained.* In this way the whole attention may be concentrated on the successive operations of the slide rule.

The position of the decimal point in the answer can easily be found with certainty by inspection and *rough* cancellation.

Thus the figures $233 \times 4 \cdot 75 \times 77 \cdot 28$
may be called $200 \times 5 \times 80$,
which is evidently 80,000 approx.

Therefore the slide rule answer is 85,500 approx.

Also in the compound fraction $\frac{3 \cdot 275 \times 1243 \times 78 \cdot 4}{0 \cdot 41 \times 7055 \times 19 \cdot 8}$,

rough cancellation gives : $\frac{\overset{8}{3 \cdot 275} \times \overset{4}{1243} \times \overset{4}{78 \cdot 4}}{\underset{6}{0 \cdot 41} \times 7055 \times 19 \cdot 8} = \frac{32}{6} = 5 \text{ approx.}$

The slide rule answer is therefore 5·56 approx.

Time and Speed Scales

17. When using a map the Navigator often wants to know the answer to one of three questions :—

(i) How far has the aircraft travelled across the map in a given time at a known ground speed ? That is,

$$\text{Distance} = \text{Speed} \times \text{Time}$$

(ii) What is the Ground Speed of the aircraft if it has travelled a known distance on the map in a given time ? That is,

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

(iii) How long will it take at a known Ground Speed to cover a known distance on the map ? That is,

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}}$$

To avoid calculating the above equations, a Time and Speed Scale can be constructed for use on any map of a particular scale. This saves time and trouble in the air and is very useful to the Pilot-Navigator who normally uses a map on which the scale is constant.

18. The construction of a Time and Speed Scale is simple. Suppose it is required for use on a "Half Million" map (see Chapter III, paragraph 8) in an aircraft with a possible speed range of from 100 to 300 m.p.h.

In 20 minutes at 120 m.p.h. (a convenient speed for simple calculations) the aircraft will travel 40 miles. This is a distance of $\frac{40 \times 63,360}{500,000}$ inches, or 5.0688 inches on the map. Similarly at 300 m.p.h. the distance travelled in 20 minutes will be 100 miles, i.e. $\frac{100 \times 63,360}{500,000}$ inches, or 12.672 inches on the map. Alternatively these distances can be taken from the scale on the map.

19. Draw a vertical line and divide it into 18 equal parts, writing speeds against the divisions for every 10 m.p.h. from 120 to 300 m.p.h. Draw horizontal lines from each division. On the top line, mark off a distance of 5.0688 inches. Divide this length into two equal parts and sub-divide one of these into five equal parts. On the bottom line, mark off a distance of 12.672 inches from the vertical line, dividing this length as in the previous case. Now join the divisions on the top line to those corresponding on the bottom line. Extend these vertical lines above the top horizontal line so as to accommodate the speeds lower than 120 m.p.h.

20. The smaller horizontal divisions of any one line represent the distances travelled in individual minutes, while each whole line represents the distance travelled in 10 minutes, at the limiting speeds. Since the intermediate horizontal lines are all divided proportionally, the divisions upon them also represent appropriate distances travelled at various intermediate speeds in one-, or ten-minute intervals.

21. To enhance the practical value of such a Time and Speed Scale, a second scale may be made for the lower speeds of the Wind, this scale being mounted alongside the main scale as illustrated in Figure 7. Both scales may be used together when keeping an Air Plot. In practice it will not be necessary to allow for such an extensive speed range as shown.

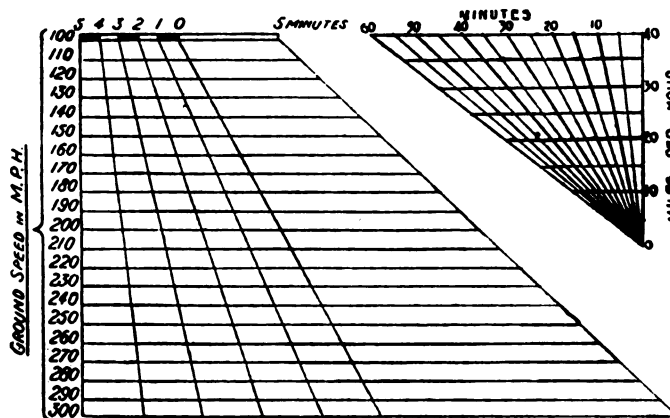


FIGURE 7. Time and Speed Scales.

Vector Parallelogram and Vector Triangle

22. A body may be subject to more than one velocity at the same time. Consider the case of a ship steaming at 6 knots up a river that is flowing at 2 knots. The ship has two velocities at the same time, and its progress in relation to the ground will be the result of the two velocities, namely 4 knots up-stream.

23. When two or more velocities act simultaneously on a body it is said to have a *resultant* velocity due to the two or more *component* velocities. In the example cited, the ship has a resultant velocity of 4 knots up-river, for the component velocities are acting in the same line, though in opposite directions, and it is clear that the resultant is the *difference* between them. If the ship was steaming down-stream the *sum* of the velocities, 8 knots down-stream, would be the resultant velocity.

24. When the component velocities do not act in the same line, the resultant velocity will be a certain speed in an intermediate direction. In such a case the resultant velocity can be found by constructing a vector diagram in the form of a parallelogram whose sides are the vectors of the component velocities.

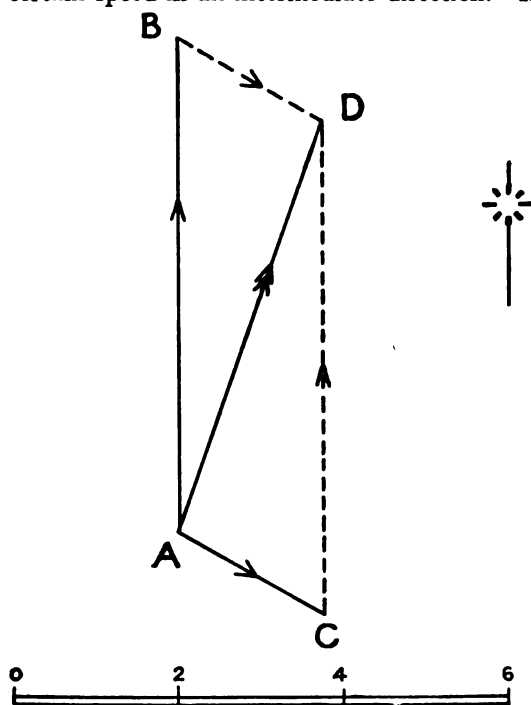


FIGURE 8. Vector Parallelogram.

25. For example, a ship is steaming North at 6 knots in a tide running at 2 knots from 300° T. Figure 8 shows AB, the component vector of the ship's velocity; and AC is the component vector of the tide's velocity.

26. A parallelogram ABDC is constructed on AB and AC, and the diagonal AD is drawn. AD is then the vector of the resultant velocity, which is found by measurement to be 5.3 k in a direction of 019° T. It should be noted that two identical triangles form the vector parallelogram.

27. It is easiest to understand how the resultant is derived from two or more simultaneous velocities if actual distances are considered, instead of velocities. That is, using the scale of distance in Figure 8, it will be seen that the ship travels from A to B in the water in one hour. At the same time the water has travelled a distance from B to D. Therefore after one hour the ship is at D. This is true whatever unit of time is used.

Consequently the ship must move along the line joining A to D at a speed of AD knots, as long as its component velocities remain as stated.

Vectorial Addition

28. A general rule may now be stated with regard to component velocities:

When a body is subject to two or more component velocities, its resultant velocity is found by applying the component velocities in turn.

In other words, the resultant vector is the *sum* of the component vectors.

Two Velocities

29. Taking the example already used, consider the two simultaneous velocities as though they were applied to the ship in turn.

First the ship's velocity is represented by vector AB in Figure 9 (a). Now apply the vector BD representing the velocity of the tide. It follows that AD is the resultant velocity of the ship.

If the velocity of the tide is applied first, AC is drawn, in Figure 9 (b), and CD is then drawn representing the velocity of the ship. The same resultant AD is obtained, in whichever order the component velocities are applied.

30. It must be obvious that there is no need to construct the vector parallelogram when the resultant velocity of any two velocities may be more rapidly obtained from *either* vector triangle.

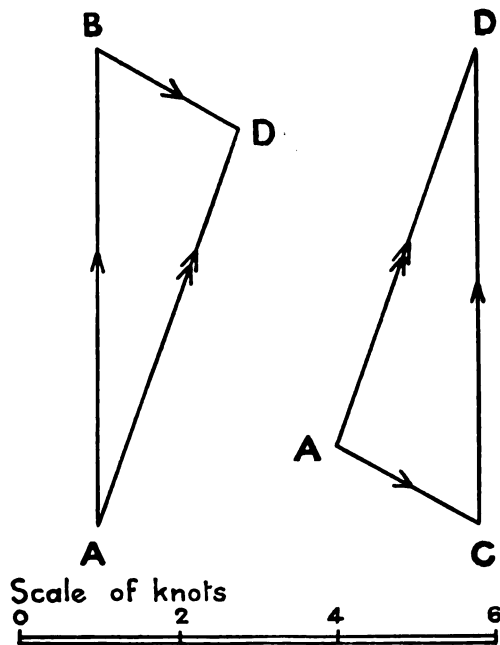


FIGURE 9. Vector Addition, Two Velocities.

It should be carefully noted that vectors add up when their directions *follow one another*. The resultant vector always opposes the direction of the component vectors (See Figure 9). This explains how apparently different triangles give the same result.

Three Velocities

Example :—

31. A ship steaming at 10 k on a Course of 035° T, is carried with the tide at 4 k in a direction of 102° T, and at the same time a gale causes it to make leeway to starboard (i.e., in a direction of 125° T) at a speed of 2 k.

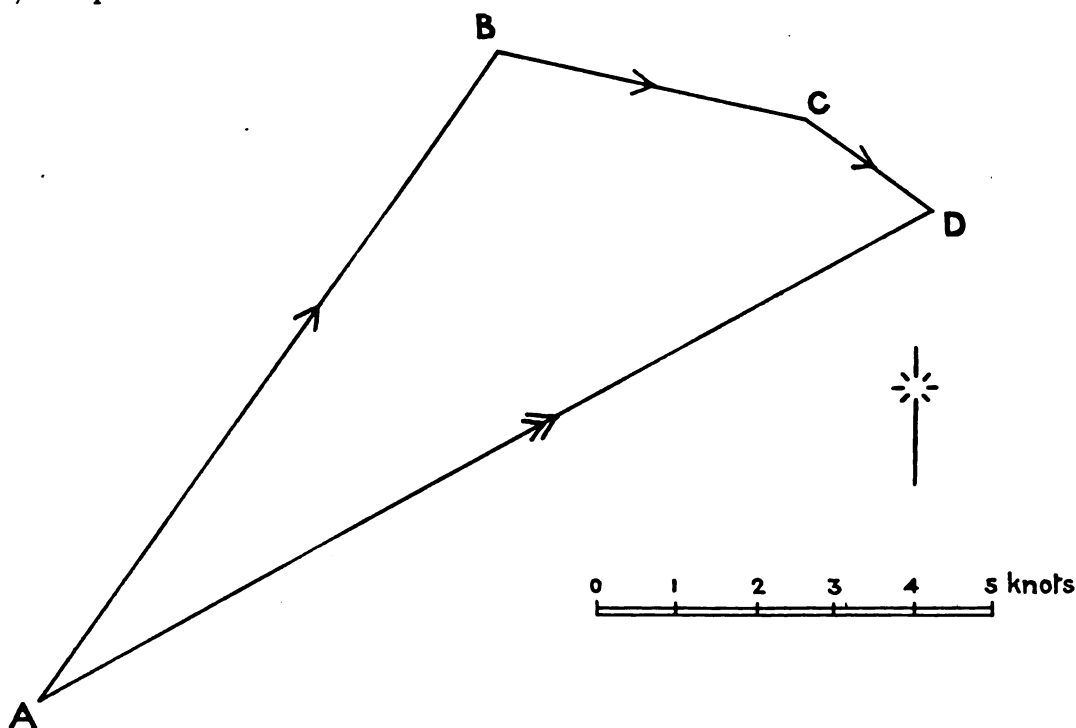


FIGURE 10. Vector Addition, Three Velocities.

In Fig 10 the three component velocities are applied *in turn*.

AB represents the ship's velocity.

BC represents the tide's velocity.

CD represents the "leeway" velocity.

Therefore AD represents the resultant velocity of the ship, namely 061° T, 12.8 k.

Vector Mean

32. When a number of velocities are operative in sequence, they may be reduced to a mean velocity.

Example :—

33. An Air Navigator who intends to climb steadily on his required track after taking off, is informed that the upper winds will change with altitude, and that he will encounter four distinct Wind Velocities during the climb. These are :

- | | |
|-----------------------------------|-----------------------|
| (i) Ground, up to 2,000 ft., | $240^\circ/20$ m.p.h. |
| (ii) 2,000 ft., up to 4,000 ft., | $270^\circ/30$ m.p.h. |
| (iii) 4,000 ft., up to 6,000 ft., | $300^\circ/40$ m.p.h. |
| (iv) 6,000 ft., up to 8,000 ft., | $350^\circ/30$ m.p.h. |

If the ascent is made at a constant rate of climb, what Wind Velocity should be applied during the climb?

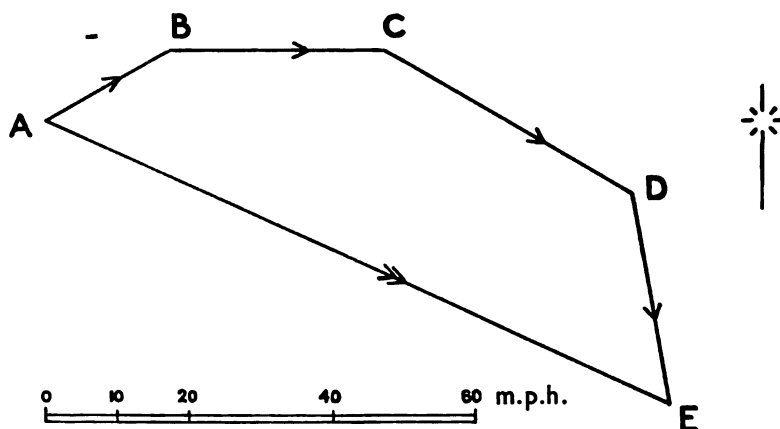


FIGURE 11. Mean Velocity.

34. Figure 11 shows the derivation of the (resultant) mean Wind Velocity. AE represents the Wind effect *in four hours* on the aircraft during its climb, namely 96 miles from 294° T. To obtain the Wind Velocity applicable during the climb, divide AE by 4. Thus the Wind Velocity is $294^{\circ}/24$ m.p.h.

Such a Wind is sometimes called a *Mean Equivalent Wind*.

Arithmetic Mean versus Vector Mean

35. The arithmetic average of a number of velocities may or may not differ appreciably from their average obtained by a vector construction according to the degree of difference or similarity between the directions of the various velocities. Thus the arithmetic mean of the Winds in the previous example is $290^{\circ}/30$ m.p.h. The vector mean Wind is shown to be $294^{\circ}/24$ m.p.h., which is considerably different from the arithmetic mean.

36. The vector mean should always be used in preference to the arithmetic mean; but there are a few occasions when the latter may be used to save time without introducing serious errors. Thus when a number of Navigators have been operating in the same area at the same time and at the same height, a reliable representative Wind can be obtained by an arithmetic average of the various Winds found. If any great divergence exists in the Wind directions found in such circumstances, the conclusion can be drawn that the divergent Winds are unlikely to be correct any way, and should therefore be rejected.

Solution of Vector Triangles

37. The Navigator soon discovers that many of the problems arising in flight concern the determination of the various velocities that affect the aircraft in relation to the ground or to other craft. It should be apparent from what has already been said that a simple solution of velocity problems lies ready to hand in the vector triangle.

38. A triangle consists of six parts, having three sides and three angles. A knowledge of any three of these parts, except when these are the three angles, enables all the other parts to be calculated. The triangle could be solved using trigonometry. Fortunately this is not the only possibility, and the Air Navigator finds that a graphical solution, by constructing the vectors on paper, gives him the answer with sufficient accuracy for his purpose. More commonly still, the triangle may be solved by mechanical instruments, capable of adjustment to accommodate any given data. This is true of the most usual velocity problems met in flight; but naturally some data may exceed the limitations of the settings on these instruments, and consequently not all problems may be solved mechanically *in practice*.

39. There are only four possible types of problem on the vector triangle. The unknown parts may be :—

- Either (i) The length and direction of one side ;
- or (ii) The length of one side and the direction of another ;
- or (iii) The lengths of two sides ;
- or (iv) The directions of two sides.

The Length and Direction of One Side Unknown. (Case (i).)

Example :—

40. An aircraft flying at a True Airspeed of 250 k on a Course of 293° T encounters a Wind Velocity of $340^\circ/25$ k. What is the Track and Ground Speed ?

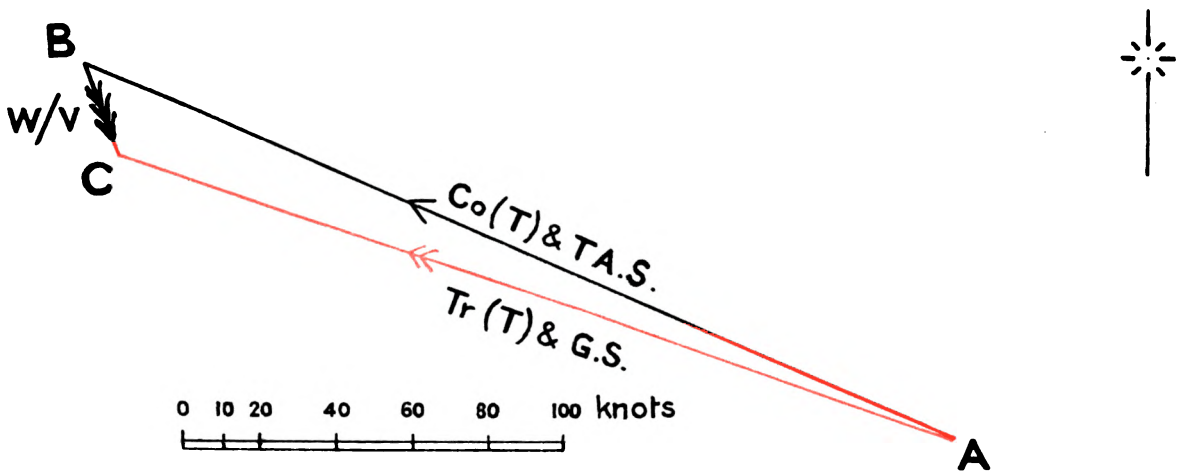


FIGURE 12. Solution of Vector Triangles: Case (i).

Solution. (See Figure 12.)

41. Draw AB, the Course and Airspeed vector, and from B lay off the Wind vector BC.

Join AC, representing, in direction and length, the Track and Ground Speed respectively, namely 289° T, 233 k.

The Length of One Side and the Direction of Another Unknown. (Case (ii).)

42. This is a class of problem very frequently encountered by the Air Navigator, who, being given the True airspeed, Track and Wind Velocity, has to work out the Course to steer and the consequent Ground Speed.

The most common solution is to construct the opposite triangle of the Parallelogram of Velocities to that used in paragraph 41 above, because it is more logical to begin at the beginning, and to make allowance for the Wind at the start of a flight. The beginner must not stumble over the apparent inconsistency in construction between the two solutions; as was seen in paragraph 26 above, both triangles are identical though one is sometimes more convenient to use than the other.

Example :—

43. An aircraft cruises at a True Airspeed of 200 k and it is desired to fly along a Track of 080° T. If the Wind Velocity is $310^\circ/40$ k, what will be the Course T and Ground Speed ?

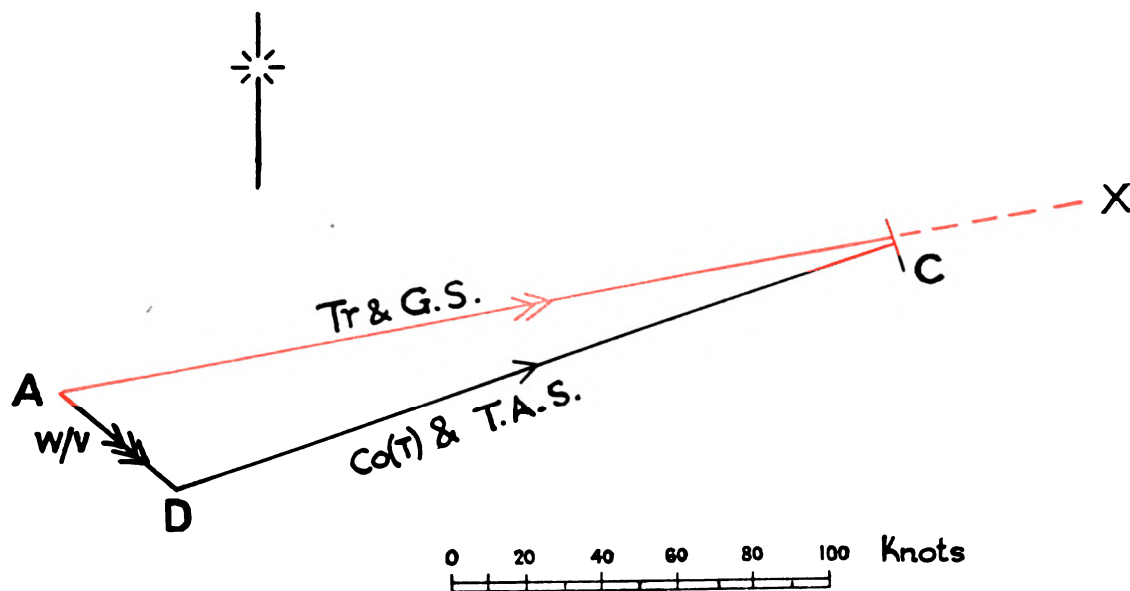


FIGURE 13. Solution of Vector Triangles, Case (ii).

Solution. (See Figure 13.)

44. Draw the Track AX in a direction 080° T. From A, lay off AD, the Wind vector to scale. With centre D and radius True Airspeed to scale, cut AX with an arc at C. Then DC in direction gives the Course, which is found to be 072° T.

The Ground Speed is given by the length of AC, to scale, i.e. 222k.

The Length of Two Sides Unknown. (Case (iii).)

Example :—

45. The Navigator of an aircraft cruising over the sea at 260 k on a Course of 195° T observes 5° drift to Starboard. The direction from which the Wind is blowing is observed from the surface of the sea to be 085° T. What is the Ground Speed and Wind Speed ?

Solution. (See Figure 14.)

46. Draw the Course and Airspeed vector AB. Draw AX, the track being made good, i.e., in a direction 195° T + 5° = 200° T.

Through B draw YZ in the direction to which the Wind is blowing, i.e. 085° T $\pm$ 180° = 265° T. This line cuts AX at C.

Then AC is the Track and Ground Speed vector, the Ground Speed being 269 k.

BC is the Wind vector, the Wind Speed being 25 k.

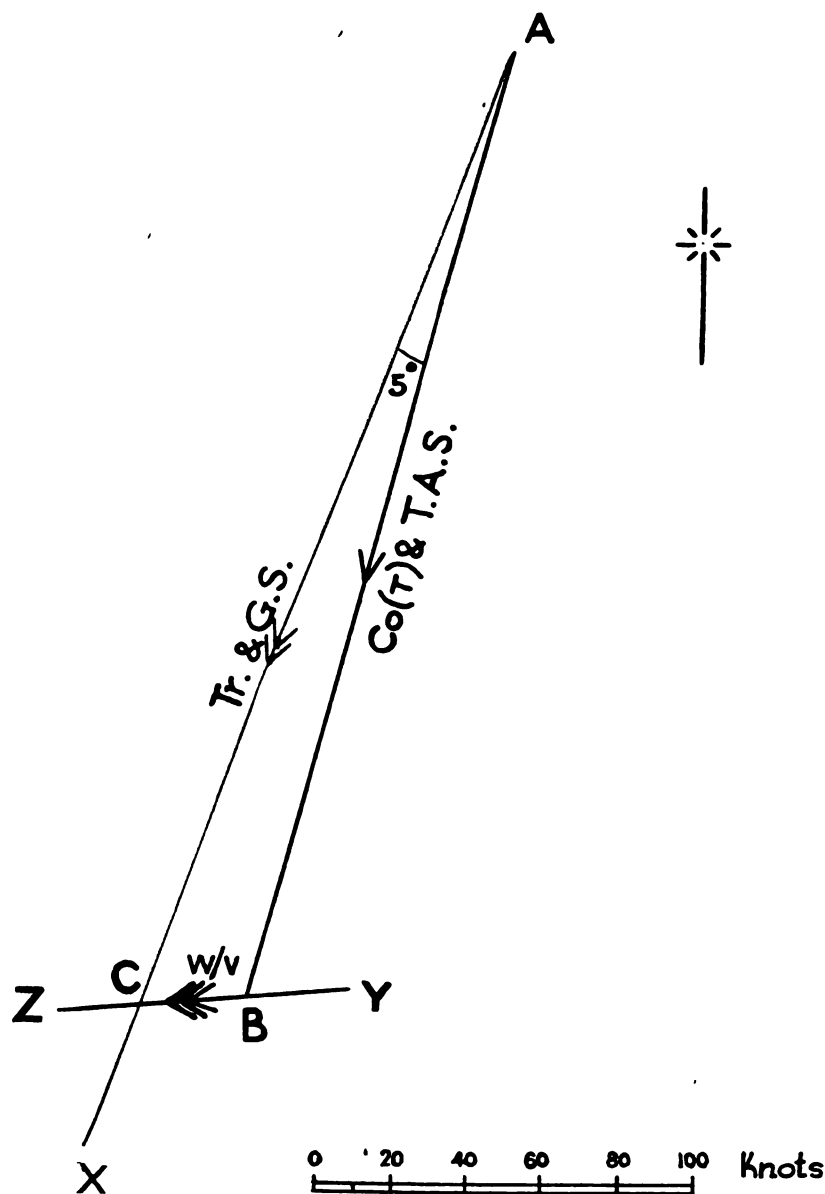


FIGURE 14. Solution of Vector Triangles, Case (iii).

The Direction of Two Sides Unknown. (Case (iv).)

47. This case does not arise in practice, but is included to demonstrate the fundamental principles.

Example :—

An aircraft on a Course of 090° T flies at a True Airspeed of 250 k. The Ground Speed is known to be 264 k and the Wind Speed is known to be 26 k. What are the Wind Direction and Track made good?

Solution. (See Figure 15.)

48. Draw AB, the Course and Airspeed vector. With centre A and radius the Ground Speed to the chosen scale, strike an arc on either side of AB.

With centre B and radius the Wind Speed to the same scale, cut the arcs already drawn at C and D.

Then either AC or AD is the vector of the Track and Ground Speed, the Track being 085° T or 095° T.

Either BC or BD is the Wind vector, the direction being 209° T or 331° T.

The ambiguity may be dispelled if drift can be measured, or the probable direction of the wind deduced from other indications.

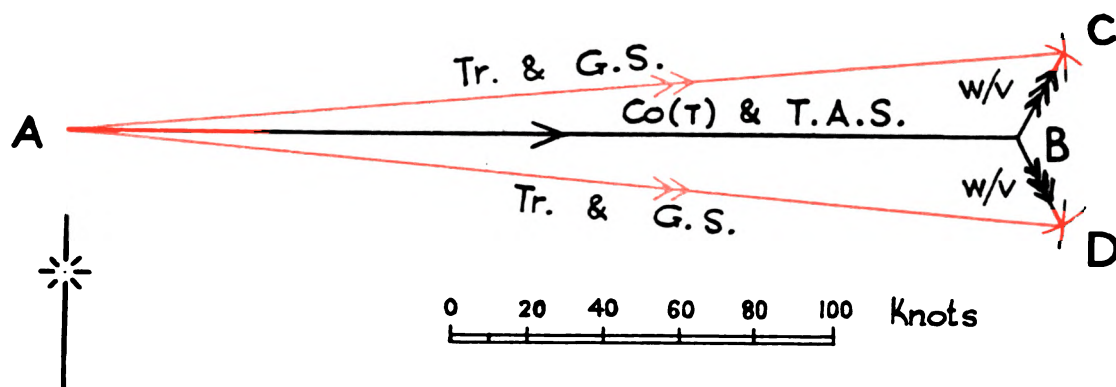


FIGURE 15. Solution of Vector Triangles Case (iv).

Relative Velocity

49. So far the flight of an aircraft has been considered only in relation to fixed objects on the ground, and it may be clear by now that this aspect of flight is concerned with two simultaneous component velocities, namely (i) Course and Airspeed, and (ii) Wind Velocity, both of which act at the same time on the aircraft and produce a third, resultant velocity, called (iii) Track and Ground Speed. The Navigator flying to a stationary destination will only be concerned with these three primary velocities which he repeatedly resolves into vector triangles to meet the problems that arise on the journey.

50. However, if the progress of an aircraft is regarded in relation to another moving object, the aircraft may be said to have a fourth velocity, in addition to the three mentioned above. This fourth velocity is known as *Relative Velocity*, a term that may lead to some confusion since *all* velocities are *relative* to something. Relative Velocity however only defines the relationship between two moving bodies.

51. It is important to realise at once that no great difficulty is introduced into velocity problems by a fourth simultaneous velocity. At the same time it may be helpful to examine one or two features of the relationship between the two moving bodies that distinguish the primary velocities from this "secondary" velocity. Take the case of two trains moving on the parallel lines of a train ferry:—

(i) Both trains may be stationary or moving in the same direction, at the same speed ; in which case there is no "relative velocity."

(ii) Train A may be moving towards the bow at 3 m.p.h., while train B moves at 3 m.p.h. astern. In this case the "relative velocity" of train B considered from train A is 6 m.p.h. astern ; while from B, train A has a "relative velocity" of 6 m.p.h. ahead.

(iii) Train A may be moving astern at 3 m.p.h. while B is moving at 2 m.p.h., also astern. Then train B appears from A to be going forward at 1 m.p.h., while train A appears from B to be going astern at 1 m.p.h., both being "relative velocities."

(iv) Throughout all these operations the train ferry may have left one port and arrived at another. No effect on the Relative Velocities will be observed in any case ; e.g., the ship is moving, say, South at 10 m.p.h. when train A is going astern at 2 m.p.h., and train B is going ahead at 1 m.p.h. Train A therefore has a speed towards the South of 10 m.p.h.—2 m.p.h. ; while train B is going at 10 m.p.h. + 1 m.p.h. to the South. Thus to A, train B has a Relative Velocity South at 11 — 8, that is at 3 m.p.h. ahead. While to B, train A has a Relative Velocity of 8 — 11 m.p.h. = — 3 m.p.h. to the South, that is 3 m.p.h. to the North, or astern.

52. Three important rules emerge from these illustrations :—

(i) The velocity of one moving body relative to a second moving body is *equal but opposite* to the velocity of the second body relative to the first.

(ii) The Relative Velocity between two moving bodies is dependent upon their respective velocities *in the same medium*. These velocities are in a sense components, of which the Relative Velocity is the resultant.

(iii) The Relative Velocity between two moving bodies is independent of any velocity that is applied equally to both bodies.

53. Consider the case of an aircraft flying at a True Airspeed of 240 k on a Course of 270° T. A second aircraft B is flying at 300 k on a Course of 360° T. There is no wind and both aircraft arrive at C at the same moment.

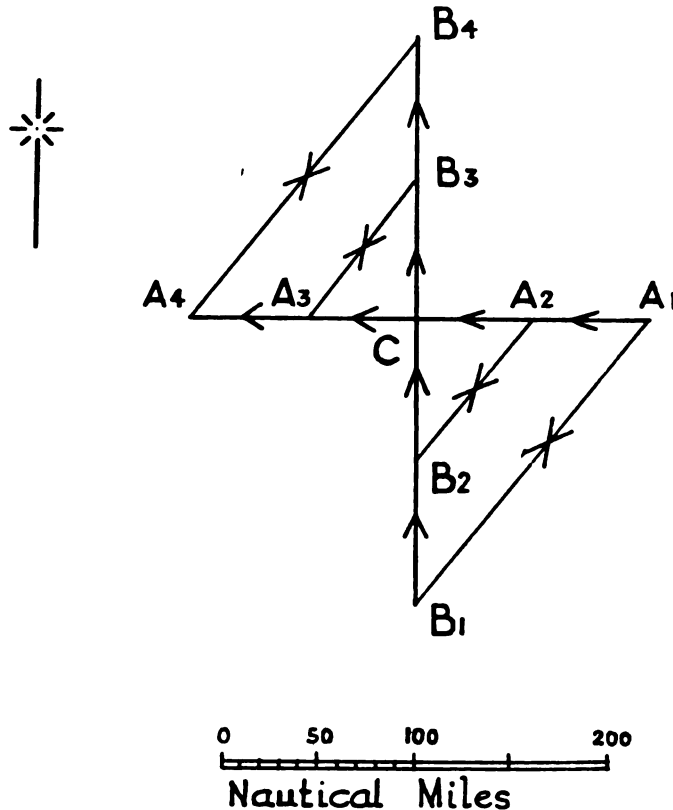


FIGURE 16. Relative Velocities.

54. Figure 16 shows the progress of the two aircraft *before* and *after* meeting, at intervals of 15 minutes. It can be seen that A and B close together and subsequently open out along a *constant bearing*, A_1B_1 , or A_2B_2 , etc.

Moreover, since their distance apart diminishes at an even rate ($A_1B_1 = 2 A_2B_2$) until they meet at C (after which it increases at an even rate) there is a *constant speed* at which they close together and open out. Their Relative Velocity may now be clearly defined, as follows :—

The Relative Velocity between two intercepting objects is the speed with which they open or close along a line of constant bearing.

55. It should be remarked that if either the speed of opening or closing, and/or the line of constant bearing between the two moving objects changes, the Relative Velocity is changed, but there is still a Relative Velocity. Moreover in the example cited above, neither aircraft actually flies along the line of constant bearing. The Relative Velocity may therefore be regarded as a *relative Ground Speed* along a *relative Track*.

56. Two further practical conclusions can be drawn from the foregoing :

- (i) If the line of bearing between two moving objects remains unchanged and their distance apart diminishes, the objects will meet.
- (ii) If two moving objects depart from a common point and maintain their individual velocities, they will open out at a constant speed along a line of constant bearing.

Solution of Relative Velocity Problems

57. The problem of determining a resultant velocity from two component velocities has already been examined in this Chapter. It has been seen that when two component velocities act in the same or in a reverse direction, the resultant velocity is simply the sum or difference respectively of the component velocities. On the other hand, when two component velocities act in divergent directions, the resultant velocity may be deduced by constructing a vector triangle.

58. Exactly the same principle is applied in solving problems of Relative Velocity as when primary velocities are concerned. It is, however, of vital importance to realise that the component velocities are not quite what they appear to be at first sight. One more illustration is necessary to show them in their true light, and indeed the whole theory of Relative Velocity hinges on the following idea :—

To a moving observer, stationary objects seem to have an *equal but opposite movement*. Similarly, to a moving observer, moving objects appear to have an equal but opposite movement, *in addition to* their own individual movements.

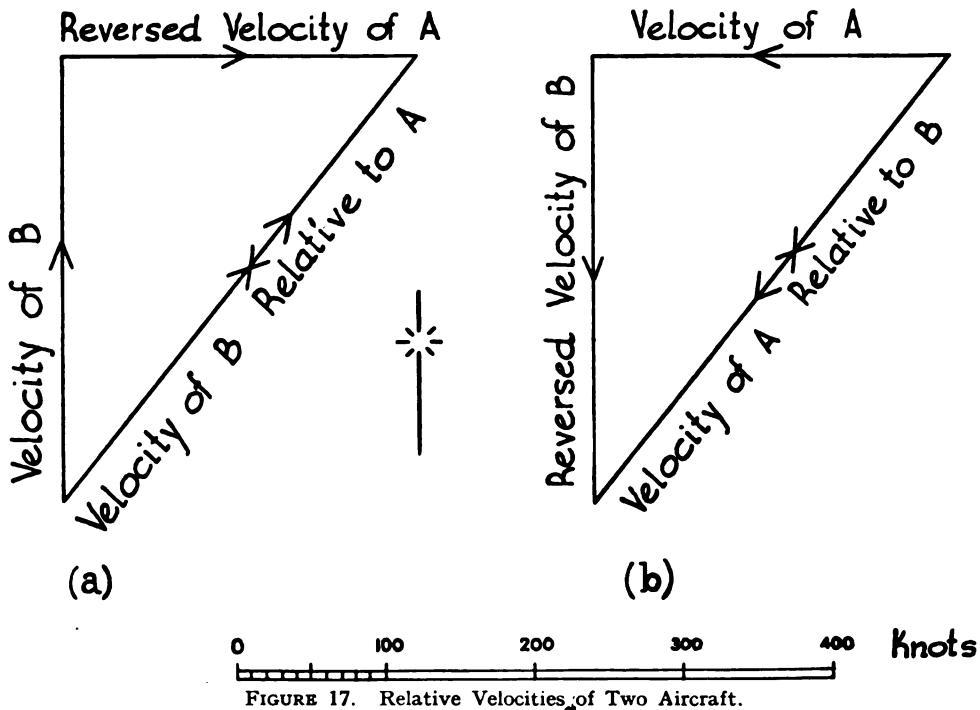


FIGURE 17. Relative Velocities of Two Aircraft.

59. Take the case of the two aircraft A and B in the previous example. Considered from aircraft A, B has its own velocity, and a velocity *equal but opposite to that of A*. Figure 17 (a) shows the velocity of aircraft B relative to A.

Now consider the same example from aircraft B. In this case A has its own velocity and a velocity *equal but opposite to that of B*. Figure 17 (b) shows the velocity of aircraft A relative to B.

60. The component velocities are seen to be the velocity of the first moving object and the reversed velocity of the second, their resultant being the relative velocity of the first from the second. With this knowledge all problems on Relative Velocity are solved by simply drawing the appropriate vector triangles. (See also Chapter X.)

The Constant Bearing Diagram

61. It has been seen that the velocity of one moving body relative to another moving body is dependent upon their respective velocities in the same medium (paragraph 52 (ii)). It often occurs in practice that the velocity of one body is given in one medium (e.g. the Track and Ground Speed of an enemy aircraft that must be intercepted) while the factors available for the solution of the problem are in another medium (e.g. the Airspeed of the intercepting fighter).

62. The first step in the solution is to convert the given data to a common medium (e.g. deduce the Course and True Airspeed of the enemy by assuming the Wind that is affecting the enemy). The vector triangle may then be solved, since the given factors will be comparable.

Example :—

63. An Aircraft flying at 200 k leaves on a Track of 028° T from an Aircraft Carrier which is making good a Track of 090° T at 30 k. The Wind Velocity is $133^\circ/35$ k.

Find the Relative Velocity of the Aircraft when it is :

- (i) leaving the Carrier ;
- and (ii) returning to the Carrier.

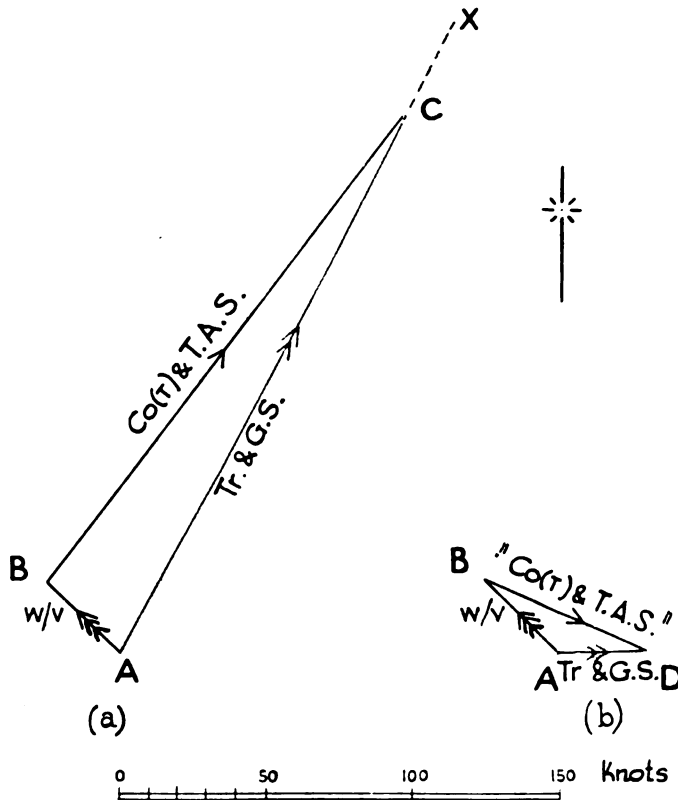


FIGURE 18. Relative Velocity between Aircraft and Ship.

Solution :—(Leaving).

64. Since the Track and Ground Speed of the Carrier, and the Track of the Aircraft leaving are known, a knowledge of the Ground Speed of the Aircraft would enable the Relative Velocity of the Aircraft as it leaves the Carrier to be constructed from two comparable velocities.

Alternatively, since the True Airspeed of the Aircraft is known a knowledge of its Course and of the *imaginary* Course and True Airspeed of the Carrier would also give the required Relative Velocity.

In fact, it is from the latter data that the solution is found, because in any case the Course to make good the Track of 028° T must first be calculated as an essential step to finding the Ground Speed of the Aircraft.

65. Figure 18 (a) shows the derivation of the Aircraft's Course and Ground Speed.
 AX is the Track required.
 AB is the Wind vector, downwind from A.
 C is where an arc of centre B and radius 200 k (to scale) cuts AX.
 Thus the Course to leave is 037° T (and the Ground Speed is 205 k).
66. Figure 18 (b) shows the derivation of the *imaginary* Course and True Airspeed of the Carrier.
 AD is the Carrier's Track and Ground Speed.
 AB is the Wind vector downwind from A.
 $\therefore$ BD is the Carrier's imaginary Course T and True Airspeed, namely 113° T, 65 k.

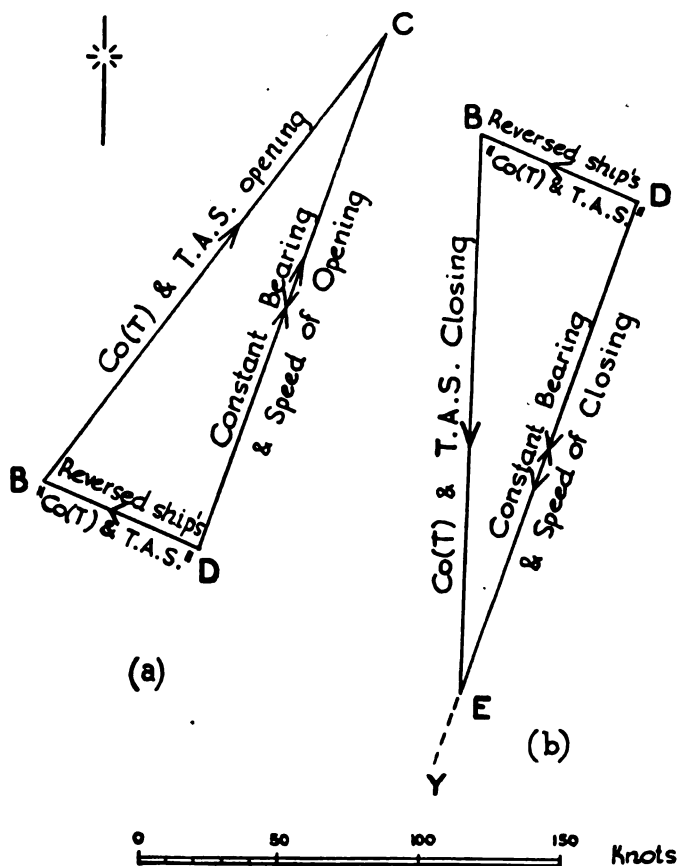


FIGURE 19. Aircraft's Velocity Relative to Carrier.

67. It is known that the Relative Velocity of the Aircraft leaving the Carrier will be the resultant of two velocities, namely the *reversed* Course and True Airspeed of the Carrier, and the Course and True Airspeed of the Aircraft. (See paragraphs 60 and 64.)

In Figure 19 (a) these two component velocities are applied in turn, i.e., DB and BC respectively. $\therefore$ DC is their resultant, the Relative Velocity of the Aircraft as it leaves the Carrier, viz. 020° T, 193 k.

Solution :—(Returning).

68. When the aircraft turns and approaches the Carrier by the most direct path, its Bearing from the Carrier will remain what it was at the moment of turning, i.e. 020° T.

The solution of the Relative Velocity of the returning Aircraft is much simplified because the Carrier's imaginary Course and True Airspeed, the Aircraft's True Airspeed, and the direction of approach (the line of Constant Bearing) are already known.

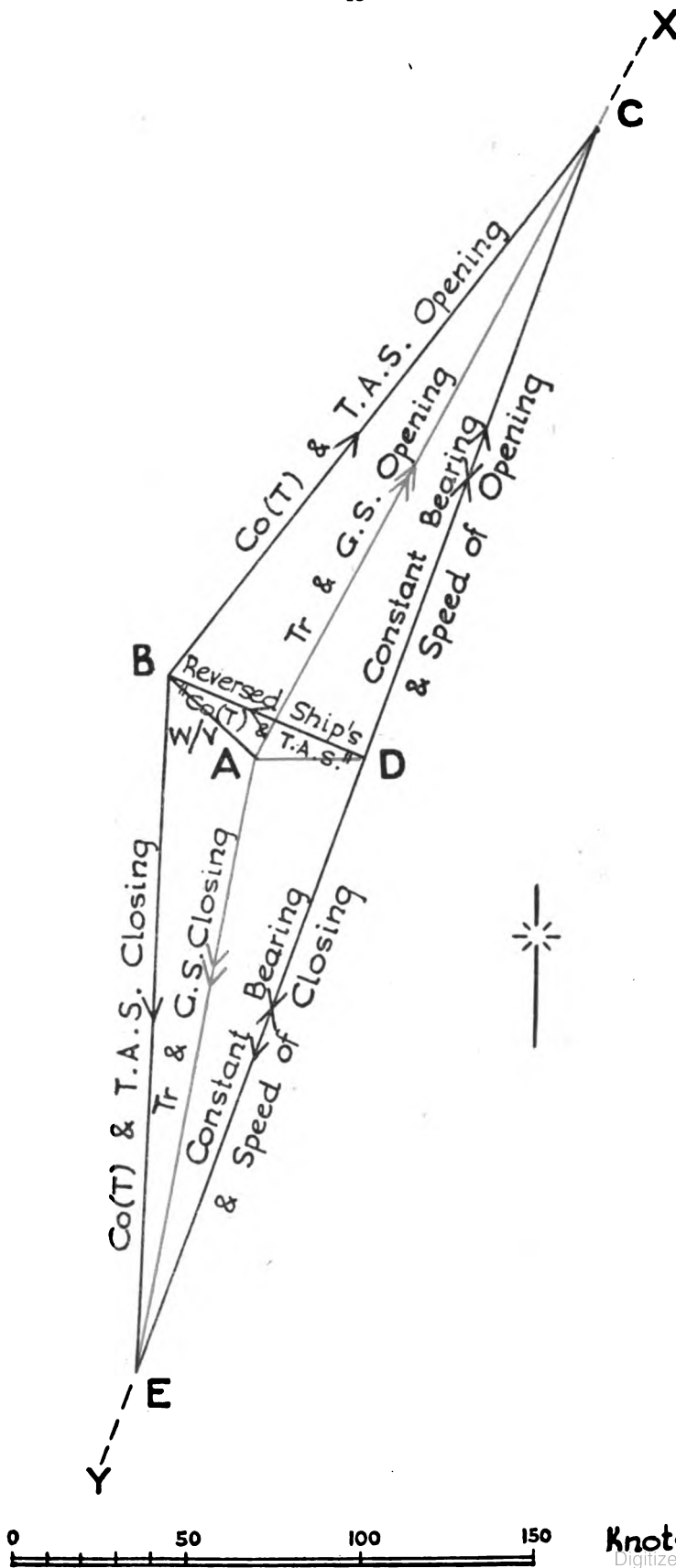


FIGURE 20. A Constant Bearing Diagram.

69. Figure 19 (b) shows the determination of the Speed of Approach (and incidentally, of the Course of the returning Aircraft).

DB is the Carrier's reversed Course and True Airspeed.

DY is the line of Constant Bearing.

E is where an arc of centre B and radius the Aircraft's True Airspeed (to scale) cuts DY.

BE represents the Course of the Aircraft, 182° T.

DE represents in length the Speed of Closing, 186 k.

The Relative Velocity of the returning Aircraft is thus 200° T, 186 k.

70. The four triangles explained under Figures 18 and 19 may be constructed much more conveniently together rather than separately. Figure 20 shows how all contribute to the complete diagram, in which the same lettering is used as in the preceding triangles.

This is known as a *Constant Bearing Diagram*, and serves admirably to show how Relative Velocity problems concerning Aircraft involve the determination of either of two pairs of comparable velocities, Tracks and Ground Speeds, or Courses and Airspeeds.

CHAPTER III

MAPS AND CHARTS

*"What's the good of Mercator's North Poles and Equators,
Tropics, Zones and Meridian Lines?"
So the Bellman would cry: and the crew would reply
"They are merely conventional signs!"*

THE HUNTING OF THE SNARK.

Representing the Earth on Paper

1. It is impossible to wrap a flat piece of paper smoothly round a globe, or even part of it; conversely it is equally impossible to flatten out the surface of a globe or part of it, and yet maintain all the properties of its spherical surface. The map-maker has a choice as regards which qualities of the Earth's spherical surface he may wish to depict truthfully. At any one time he will be able to safeguard one or two, but not all of the following:—

- (i) Shapes.
- (ii) Great Circles.
- (iii) Areas.

(If only a very small part of the Earth's surface is taken at a time, a general compromise may be possible.)

The preservation of truth of area is of no concern to the Air Navigator who is interested only in maps which show shapes or great circles correctly. The methods used in representing the surface of the Earth on paper are called *Projections*. The very complicated mathematical computations involved are the work of a specially trained staff.

Maps and Charts are sometimes spoken of as though a vast difference existed between them, but this distinction serves no useful purpose since it only arises from the fact that maps show land areas while charts show sea areas. The *details* of each are naturally quite different, but that is as far as the distinction goes, for the projection may be identical in each case. For the purposes of this book, projections will be treated under two main headings, from which the would-be Air Navigator may judge the relative importance to attach to each:—

- (i) Topographical Projections (for map-reading),
- and (ii) Navigational Projections (for Plotting).

Topographical Projections

2. There are a very large number of projections designed solely to show the features of the Earth with a minimum of distortion. A belt of country like that through which the Nile flows, extends relatively further north and south than east and west, presenting a different problem to the map-maker from that of the country along the Canadian-American Frontier, which extends a much greater distance east and west than it does north and south; each calls for special treatment. Again, a country may be projected in different ways for different purposes, such as to preserve truth of area, of bearing, or of shape. The most usual projections are Lambert's Conical Orthomorphic, the Modified Polyconic, and the Transverse Mercator. These all differ from each other in such very minor details that, at the scales of the maps that are provided for him, the Air Navigator would find it impossible in practice to distinguish between the characteristics of the various topographical projections. Therefore for the purposes of this Manual all topographical projections are considered together; and it should be remembered that the exact reasons for the employment of one projection rather than another do not in any way concern the practical Air Navigator.

3. It so happens that most topographical maps are produced on an orthomorphic projection ("correct shape") simply because the Army likes to use this kind for its Artillery. On grounds of economy the maps provided for the Royal Air Force were, in the past, adapted from existing maps rather than designed to suit the Air Navigator's requirements. This was not by any means ideal, and it has led to the incorrect use of such maps. *Strictly speaking, they should not be used for navigation plotting purposes*, not so much because they are covered with detail that makes plotting difficult to see, but because lines drawn on them do not represent rhumb lines on the Earth (see Chapter I, paragraph 12).

Navigational Projections

4. Navigation can be carried out without reference to a map or chart, but most Navigators will agree that any map is better than none where plotting is concerned. For a very long time the Air Navigator has had to make use of virtually *any* map, but at last his special requirements have been recognised and maps have lately been produced using a projection peculiarly suited to his purpose. One of the first men to develop a projection for Navigators was a Belgian, named Gerard Kremer, who, under the *nom de plume* "Mercator" (merchant), published in A.D. 1556 a navigational plotting chart showing rhumb lines, along which the trade of the World was just beginning to flow, as straight lines. His projection has been used ever since for Navigation, and is fully explained later in this Chapter.

5. Air Navigators are primarily interested in rhumb lines, but they frequently have to consider great circles, as, for example, when plotting bearings of an aeroplane obtained by a D/F Station. Again, when planning a long flight it may be desired to study the implications of following a great circle track rather than a rhumb line track. Obviously it is a great advantage on such occasions to have a map on which all great circles can be drawn as straight lines, even though shapes and areas may be badly distorted.

6. A map produced on a *Gnomonic* projection provides these very facilities. Admiralty Chart No. 5029 supplies a means of plotting any great circle track as a straight line between two places on the Earth. Because shapes are unavoidably distorted, bearings are incorrectly represented, except those drawn from the point of origin of the projection. This difficulty can be overcome by having appropriately distorted protractors, designed to measure bearings at places other than the point of origin of the projection. A further limitation of usefulness is imposed by there being no proper scale on gnomonic maps. Distances cannot therefore be easily measured.

The Limitations of Topographical Projections

7. The topographical maps available provide almost perfect facilities for map-reading, for which purpose only they should be used. With the provision of excellent navigational plotting maps there

is little excuse for the continued employment of topographical maps on any occasion that demands a plot being kept. If the Air Navigator is under the unfortunate necessity of being compelled to use them on such occasions, he should make certain that the following properties of topographical projections are clearly understood :—

- (i) The scale of distance can be considered as constant all over each separate sheet.
- (ii) For all practical purposes, straight lines most nearly represent great circle arcs.
- (iii) Bearings of and distances along such straight lines are most nearly *great circle bearings* and *great circle distances*.
- (iv) A rhumb line drawn E and W between two places on a topographical map curves towards the Equator, in order to meet successive meridians at the same angle (see Chapter I, paragraph 12). If then, the Air Navigator is flying on a rhumb line track, in any direction but due North or South, he must expect to be on the Equator-side of the straight line he has drawn to represent his required track. The amount he will seem to be "off" this required track will depend on the inclination between the meridian of the point of departure, and the meridian of the destination. (This angle of inclination is called *convergency*, of which more later.) Thus, even on a short journey, say across Southern England, he should, when half-way across, where the "error" is most marked, expect to be nearly 2 miles off the track he has drawn. For longer journeys the "error" is correspondingly greater.

Before dealing with the legitimate use of topographical maps it will be necessary to consider the elementary questions of Scale, Conventional Signs and Relief.

Scale

8. The ratio between a given length on the map and the actual distance this represents on the Earth is called the scale of a map. That is to say :

$$\text{Scale} = \frac{\text{Map Length.}}{\text{Earth Distance.}} \text{ expressed in the same units.}$$

The ratio may be shown in one or more of three ways on a map, as follows :—

(i) A *representative fraction* expresses the ratio of a unit length on the map to its corresponding number of similar units on the Earth.

Thus One/Half Million means that 1 unit on the map is equivalent to 500,000 such units on the Earth. If the unit is an inch, one inch on the map represents 500,000 inches (7·89 statute miles) on the Earth.

(ii) A *statement in words* gives the corresponding values of two *different* units of length, one on the map and the other on the Earth. For large-scale maps, the length on the map corresponding to a mile on the Earth is usually stated, e.g. "Six Inch," "One Inch," "Half-Inch" or "Quarter-Inch." On small-scale maps, the length on the Earth corresponding to an inch on the map is more usual, e.g. "Ten-mile," "Eight-mile," and so on.

(iii) A *graduated scale line* is always given, showing the actual lengths on the map corresponding to various distances on the Earth, e.g., see Figure 1. .

These distances are usually expressed in statute miles, nautical miles and kilometres.

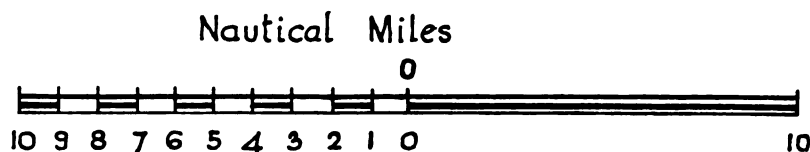


FIGURE 1. A Graduated Scale Line.

It should be noted that a scale of nautical miles is nearly always provided by the graduations of the marginal meridians.

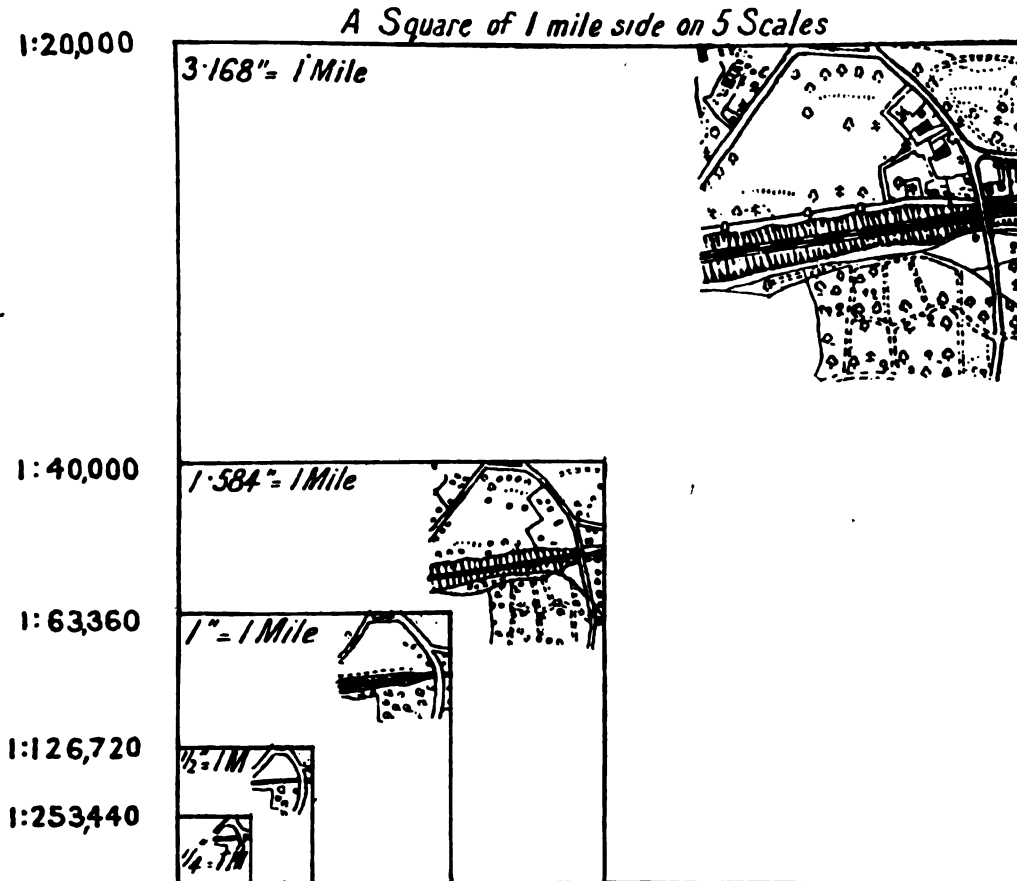


FIGURE 2. The Relationship between Scale and Detail.

9. Scale has a very close connection with the amount of detail that can be shown on any map. Obviously a map drawn on a scale of 6 Inches to the Mile affords incomparably more detail than a Quarter-Inch map. On small-scale maps a certain distortion is necessary to make the map at all readable, for if the details were recorded true to size they would be almost imperceptible on any but the largest-scale maps. At a scale of $1/250,000$, roads would be the thickness of spider's web. In fact, they may be represented as 200 yards wide, and the map-reader would be the first to complain if they were not. As the scale decreases, so the features become less and less true to form and increasingly conventionalised. A glance at Figure 2 will help drive home this point.

Relief

10. The Navigator is considerably interested in mountains and hills because they are often valuable landmarks as well as being at times highly dangerous barriers to flight. Moreover, changes in the depth of the sea may often be seen from the air, and have their uses to the Air Navigator. Relief is indicated on maps and charts in one or more of 5 different ways :

- (i) Spot heights or depths ;
- (ii) Contours and form lines ;
- (iii) Layer tints ;
- (iv) Hachures ;
- (v) Hill shading.

Spot Heights or Depths

11. These are shown against places where the exact height above or depth below mean sea level has been measured. The datum level from which all heights are measured for maps of Great Britain is that of mean sea level at Newlyn, Cornwall. The datum for measuring depths on marine charts varies considerably, but the practical Air Navigator is likely to want only a general knowledge of sea depths.

On some maps, heights are recorded in *feet*, while on others they are given in *metres*. *The Air Navigator should be very careful to ascertain what units are used on the maps he is using.*

Depths at an average sea level are shown in feet or fathoms (1 fathom = 6 feet), and it should be borne in mind that they are modified by the state of any particular tide. The visible effect of tides is confined to shallow waters.

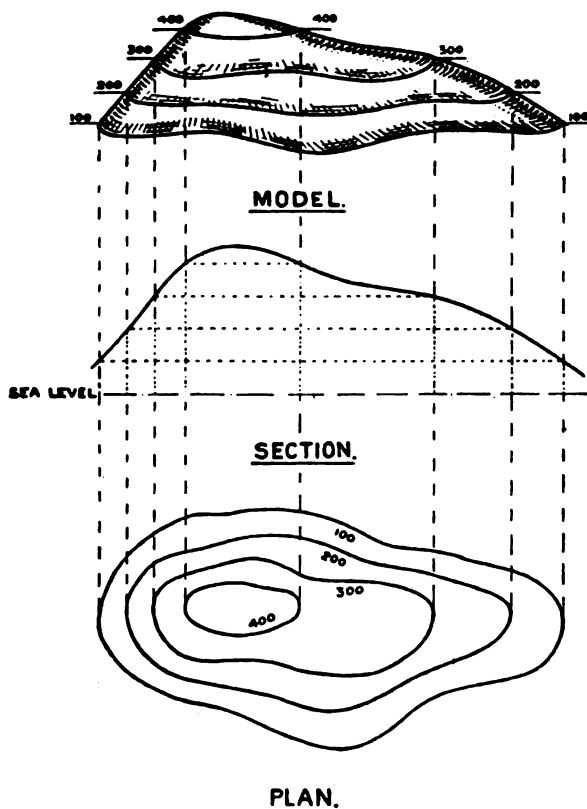


FIGURE 3. Contours.

Contours and Form Lines

12. Contours are lines connecting all places that have the same height above the datum level. When only approximately drawn, they are called form lines.

Since contours show the details of relief, it is only to be expected that more contours are to be found on large-scale than on small-scale maps. The amount of detail shown is regulated by varying the difference in level between successive contours according to the scale of the map. This difference in level between any two successive contours is usually uniform for each map series, and is called the *vertical interval*.

The Air Navigator is not concerned with the calculation of exact gradients, but should know that the closeness of contours on a map gives a good idea of the steepness of any slope. Where the change of height is rapid, the contours will be closer than where the slope is only gentle. The distance in plan view between successive contours is called the *horizontal equivalent*.

Figure 3 illustrates the principle underlying contours. It will be seen how well contours represent the various aspects of relief. It is for this reason that they are used on most topographical maps available to the Royal Air Force.

Layer Tints

13. These are commonly employed on topographical maps to give a vivid picture of relief. Layers of the Earth between certain contours are coloured distinctively, the tint usually intensifying with each successive increase in height. Thus at a glance the map will indicate the major irregularities in the surface of the country. By artificial light it is sometimes very difficult to distinguish between tints, or even to see them at all. Special colour-schemes and inks are sometimes used for ease of reading by artificial light.

Hachures

14. These are short, tapering lines drawn on the map and radiating from peaks and high ground. They only serve to show slopes, and are not used on topographical maps available to the Royal Air Force on account of their indefinite nature. However, they are employed to indicate the general form of *massifs*, on the Navigational Plotting Maps, on which accurate physical detail is not provided.

Hill Shading

15. This is produced by assuming that a bright light is shining across the map sheet, so that shadows are cast by all high ground on its lower sides. The effect is to give the map something of a

stereoscopic appearance by optical illusion. Difficulty is experienced when the shadow obliterates other detail on the map, and it is therefore, not extensively used. However, some series of topographical maps of the Continent available to the Royal Air Force have a type of hill shading.

Conventional Signs

16. There are innumerable symbols used on maps and charts to simulate physical features on the Earth either by being vaguely like what they represent or else by having been generally adopted by map-readers for the sake of convenience. Thus the sea may be shaded blue, or a lightship may be depicted in outline. There is more than an accidental resemblance between many of these conventional signs and the objects they represent, and they usually present little difficulty to the map-reader. However, as in learning a foreign language, the beginner usually has free access to a dictionary, so in map-reading he is provided with a list of the more difficult and less obvious conventional signs and their explanation, usually printed in the margins of the map sheet. These may in future be available on a separate instructional card applicable to each series of maps as a whole. It is quite obvious that, to save time and trouble, the quicker the beginner can do without the dictionary the better. He is therefore urged to spend a few minutes studying the legend in the margin of any air map.

The Position of a Light Vessel, Buoy or Beacon is the Centre of the Base, and is usually indicated by a small circle

Light Vessels or Floats			
Lights, Position of	★	★	•
Light Buoys			
Bell Buoys	 (according to shape)		
* Can Buoys			
			
* Conical Buoys			
			
* Spherical Buoys			

**In the case of two-colour buoys each colour is indicated below the appropriate symbol*

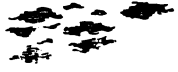
Stranded Wreck	Wreck showing any portion of the hull or superstructure above Low Water	
*Wreck	Wreck over which the exact depth known depth at Low Water is known	
Dangerous Wreck	Wreck over which the exact depth of water is unknown but which is considered dangerous to surface navigation	
Non-dangerous Wreck	*Wreck over which the exact depth is unknown but which is not considered dangerous to surface vessels capable of navigating in the vicinity	
Remains of Wreck	*Remains of a Wreck no longer dangerous to surface navigation, but to be avoided by vessels anchoring, trawling, etc	
Old Symbol	Partially or wholly submerged wreck where depth over is unknown.	
Rocks with limiting Danger line		
Overfalls & Tide Rips		

FIGURE 4. Marine Conventional Signs Useful to the Air Navigator.

17. Charts published for marine use by the Admiralty have their own special conventional signs, the large majority of which are of no importance to the Air Navigator. A complete list is available on Admiralty Chart No. 5011, a summary of which is given above for the benefit of Air Navigators operating over the sea.

Systems of Lights

18. Lights on land or at sea are of great assistance to the Air Navigator at night. Some are designed especially for this purpose, while others are only of incidental use to aircraft. Under the former category are all the lights provided in the United Kingdom, even during war time, with the aid of which the Air Navigator can check his position, provided he has the key to the secret location of the light. The light may flash alternating colours, or a Morse letter or two, and be operative only for certain hours of darkness, and its site may change from night to night. Particulars of the organisation are secret for reasons of security and are only made available immediately prior to an intended flight.

19. While marine lights are primarily for use by mariners, many can be seen from the air. Their distinguishing characteristics are, of course, secret in war time, and they may or may not operate with regularity, if at all. In peace time their characteristics are published in the *Admiralty List of Lights, Fog Signals and Visual Time Signals*, and they also appear cryptically on maps and charts. The following abbreviations are commonly used with reference to such lights :—

F.	...	...	...	Fixed.	A continuous light.
Fl.	...	...	...	Flashing.	Showing a single flash at regular intervals.
Gp. Fl.	...	...	...	Group flashing,	showing at regular intervals, a group of two or more flashes.
Occ.	...	...	...	Occulting.	A steady light with a regular total eclipse.
Gp. Occ.	...	...	...	Group occulting.	A steady light with a regular group of total eclipses.
F. Fl.	...	...	...	Fixed and flashing.	A continuous steady light varied at regular intervals by a group of two or more flashes of relatively brighter light. The group may or may not be preceded and followed by an eclipse.
Rev.	...	...	...	Revolving.	Light gradually increasing to full brilliancy then decreasing to eclipse.
Alt.	...	...	...	Alternating.	Light that changes colour.
(U).	...	...	...	Unwatched.	Such a light cannot be relied on implicitly.

20. The *period* of a light is the time elapsing between two successive identical parts of its characteristic. The period is stated in an abbreviated form. An example of the description of a light's characteristic is :—

Lt. Alt. Fl. W.R. ev. 30 sec. (U) vis. 11 M.

Such a light would show every 30 seconds, one white and one red flash. It would be visible for 11 miles, but uncertain of operation.

Note :—

(i) The visibility distance of a light is calculated for a height of eye of 15 feet. There are four factors that may affect it :—

- (a) Meteorological conditions.
- (b) Changes of refraction.
- (c) Height of the observer.
- (d) Height of the tide.

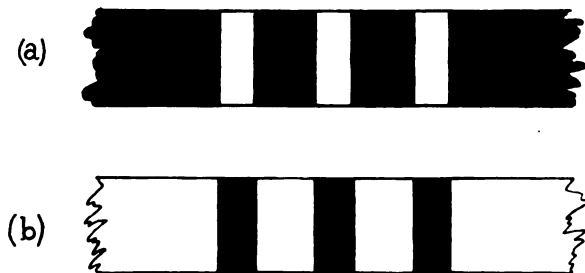


FIGURE 5. (a) Flashing and (b) Occulting.

(ii) It may be difficult to ascertain the characteristic of a light from the air since it will be seen only in plan view from directly overhead. A careful scrutiny is often necessary before identification is possible. Seen from a distance, the characteristic is usually easy to recognise.

(iii) The difference between flashing and occulting is diagrammatically shown in Figure 5.

The Use of Topographical Maps—Map-Reading

21. The fixing of position in the air by means of map-reading is of vital importance to the Navigator. While many flights are made above continuous cloud or in conditions precluding an inspection of the ground beneath the aircraft, the great majority of flights are accomplished at least to some extent in view of the ground. Ability to recognise on the map what is seen from the aircraft and vice versa is a valuable asset acquired only by practice.

22. The Navigator has a two-fold problem. First, he must be able to interpret at a glance the map or chart he is using. For this it is necessary to know by heart the conventional signs employed in cartography, as explained in the preceding paragraphs. He must realise what scale is employed on the map or chart being used, since this gives him a true perspective of features depicted on the map. The Navigator should aim at becoming proficient in reading maps drawn on any scale; for, having accustomed himself to a certain scale only, say the Half-Million series, he would, because of the difference in detail shown and the comparative speed of travel across the map, at first feel lost in

using a Two-Million map, which alone would be available for certain overseas routes. By turning the map so that the meridians upon it lie in the direction of true North and South, the Navigator will find it easier to recognise the lie of the land as drawn on his map, just as it is easier to see the likeness between a portrait and the sitter, if both are seen from the same angle. Alignment of the map in the correct direction is called "*orientation*," and by so doing the Navigator will be looking down his required track (drawn on the map) in much the same direction as his aircraft is heading.

23. Secondly, he must be able to understand the true significance of the picture presented to his gaze below. His judgment will be intuitive in its early stages, but with experience he will learn that things are not always what they seem to be. In varying conditions of season, visibility, speed and height, the same object on the ground will take on very different appearances. The Navigator must probe beyond mere appearances, and ascertain realities, relying largely on his common sense.

24. The danger of jumping to the wrong conclusion is most real when the Navigator imagines he has lost his way and cannot quickly recognise expected landmarks ; or when a landmark fails to show up at the appointed time and something similar presents itself. These moments call for self-restraint and quiet reasoning which do not always come naturally to the beginner.

25. It will be found helpful to take as wide a view of the countryside as possible, and, therefore, map-reading becomes increasingly difficult as the visibility is reduced by meteorological conditions or by low flying. This is because the inter-relationship of features on the ground is much more important than the features themselves. For example, while it is difficult to recognise a particular stretch of railway line in countries covered by railway systems such as those of Western Europe, it may be very easy to identify the railway line from its proximity to a river, a town, a hill or a wood.

26. The beginner at map-reading often finds that the time element is his chief source of trouble. Objects on the ground are presented for observation for such a fleeting moment that they often pass out of sight again without being recognised ; and after a whole succession of abortive attempts, the best will in the World begins to flag.

27. The first essential is to have a rough idea of the position of the aircraft. Obviously, the search on a map for a feature seen on the ground will be helped if the correct map sheet is being used. Searching the wrong map is not likely to happen on most flights, but it serves to indicate that the narrower the field of uncertainty, the easier pin-pointing becomes.

28. The secret of success lies in anticipating everything before it shows up. This is really quite easy, for the map-reader can study the outstanding features along the required track, *before setting off*, and also estimate the times at which he should be in various positions. This is possible because, as will be explained later, he should have more than a hazy idea of his ground speed. With one eye on his clock or watch, and the other noting the passage of significant places on the ground, the map-reader can say roughly where he ought to be at any time. By narrowing down the field of uncertainty to reasonable limits, he can anticipate what lies ahead, and as he arrives at each landmark he re-checks his progress. The problem of successful map-reading thus falls into two classes, as follows :—

(i) *Map-Reading when the approximate Position of the Aircraft is known :—*

When a Navigator knows roughly where he is and is engaged in checking his progress over the ground, he should look out for prominent features which a study of his map leads him to expect. This entails a careful study of the area of the map in use, memorising the outstanding features and finally recognising these on the ground. Such map-reading depends for success upon the existence of land or sea marks of sufficient importance to break the continuity of the scenery over which he is flying : a river flowing through a desert, a mountain rising out of low country or a coastline are a few of the more obvious examples ; but on most flights there are innumerable such features in well-mapped and highly developed countries, as in Europe.

It will be found of assistance to mark off stages along the track which the aircraft is to follow, according to the distance travelled in a selected time period. Thus if the aircraft's estimated position is marked off, say every 10 minutes, the Navigator can without delay see from his map those terrestrial features that are likely to be in view at any time. Time-Speed Scales (*see* Chapter II, paragraph 17) may be used for this purpose. Alternatively the stages may be marked off using the distance travelled during a period of time already observed by the Navigator.

(ii) *Map-Reading When the Position of the Aircraft is not known :—*

If a flight has been out of sight of the ground for some considerable time the Navigator must calculate his probable whereabouts.

He obviously knows where his point of departure was, even if he has not been able to check his position since then. By means discussed in Chapter V, he can calculate what his estimated progress has been since leaving this known position and deduce an estimated position that gives him something to work on. From this stage he looks at the map in the vicinity of his estimated position and ascertains what physical features are likely to be in view. He then looks at the country around him and endeavours to make it fit the map. This sounds paradoxical, but in fact it is only logical that the part should be made to fit the whole.

The beginner almost invariably tries to make the map fit the country, and he usually succeeds in achieving only a near fit because physical features often repeat themselves more than once on any one map sheet ; and he will have been too intent on studying the lie of the land to notice any discrepancies in that part of the map which he thinks he occupies. Another very good reason for working from the map to the country is that there may be features on the ground that are not marked on the map, whereas everything marked on a good map is invariably to be seen on the ground. Let it be said again, at the risk of being monotonous, that every care should be taken to avoid jumping to conclusions.

It will be evident to the beginner that this second class of map-reading calls for a much greater skill, and it is only by *constant practice* in handling a map that rapid and accurate pin-pointing is achieved.

Map-Reading in Poor Visibility

29. There are fewer opportunities for map-reading when visibility is poor than when good. The Estimated Time of Arrival at any prominent landmarks along a route should be calculated, and a sharp look-out kept for some time before and after this time. Pin-points are often missed through the Navigator not observing early enough.

Map-Reading at Night

30. At night the possibility of map-reading depends upon the amount of light shed by the Moon and Stars, upon the season of the year (except in tropical regions) and also on the amount of light displayed on the ground. It is normal for visibility distance to increase at night ; and lights from points that had been invisible by day may often be clearly seen at night. This leads to some confusion against which the Navigator must guard himself.

31. Ability to see in the dark is not uncommon, and it can to a certain extent be improved by practice. Once acquired, "night eyes" are best kept looking at the country below, and should not be used in a lighted cabin.

32. On all but the darkest nights, and assuming no assistance from artificial lights on the ground or in the air, it is usually possible to distinguish between water and ground, since water reflects the light of the sky, particularly when waves are breaking. Coast lines, rivers and lakes are thus of great importance, showing up pale grey against a dark background.

33. It is difficult to distinguish small details at night unless there is a large Moon. Snow on the ground is a great help in these circumstances. Low flying is of assistance, but should never be adopted if the Navigator is lost, as it is very difficult to see hills and other obstructions, and he is likely to miss seeing distant but more significant features. Objects up-Moon are easiest to see. Clouds throw deceptive shadows that look like towns over land, and like islands over sea.

34. During night operations, apart from routine navigational observations, it is essential to recognise the destination, and this is only achieved by map-reading in its vicinity. Where possible, full use should be made of co-operation between the members of the crew for map-reading under these conditions. The ground can only be seen on many nights when illuminated by parachute flares dropped behind the aircraft. It has been found very successful for a member of the crew (e.g., the Second Pilot) to keep watch on the ground through the bomb aimer's position and report the salient features seen in the light of the flares. The Navigator informs him from the Navigator's table what features he should look for, according to the estimated position of the aircraft. By co-ordinating what should be seen with what is seen, full advantage is taken of the parachute flares and successful map-reading is ensured. It is found most useful to make a turn and fly past the flare looking with shaded eyes at the country between the aircraft and the flare.

Landmarks

35. The beginner is usually confused by the wealth of detail that confronts his untrained eye. He must learn to distinguish the more significant features of the scene below him, and to remain undistracted by the irrelevant background. Some distinctive landmarks, such as large private houses, windmills, gasometers and factories, will not be marked on the map. The following may help to indicate what the Navigator should look for in particular :—

(i) *Railways*.—These are very distinctive landmarks from the air. By studying their direction, and taking into account other features—e.g., tunnels in hilly country—they afford the best general means of ascertaining position in flight. By day and night, traffic on them makes them if anything more obvious. Some light railways, and even main lines, run along, or close by, roads, especially on the Continent, and may for this reason be very difficult to see. In such circumstances an inspection of cross-roads will reveal the presence or absence of rails.

(ii) *Water*.—Rivers and lakes are given particular prominence on aeronautical maps because of their value as landmarks. Since they have distinctive shapes, generally stable over a number of years, it is usually possible to identify them without delay. However, care must be taken to avoid confusion because near their estuaries rivers sometimes resemble one another in any particular region. Moreover, flood waters may temporarily alter the size and shape of rivers and produce lakes where none are marked on the map, whilst in a drought a river may dry up completely.

By studying the flow of quite small rivers it is possible for the Navigator to decide on which side of a main watershed he is. This may be of some value where visibility has been severely curtailed for some time.

(iii) *Mountains and Hills*.—While a countryside appears to flatten out increasingly with the height of the Navigator above it, the contours of prominent mountains and hills are usually discernable. A mountain range may be visible when lower lying country is shrouded in mist, and often provides a valuable landmark for very long distances. When flying in mountain country, map-reading may be difficult by reason of the similarity of peaks or valleys. Some help may be obtained by using the height of the aircraft to estimate the height of the peaks in sight, comparing this with the heights shown on the map. Mountains tend to look higher and nearer than they are from an aircraft in their vicinity, but they should always be treated with great respect. Their crests are often shrouded in cloud, particularly on the windward side, where the air is being cooled by lifting.

(iv) *Towns and Villages*.—Towns are often easy to identify from their size, location in a valley, on a hill, or beside an estuary or bay. Confusion may arise between neighbouring towns of similar size, and especially between villages in any particular area. Owing to their rapid growth the shape of towns may not be correctly shown. A careful scrutiny of the number and direction of railway lines entering and leaving or near the town, and of roads and natural features surrounding it, will usually dispel ambiguity. Villages may be marked conventionally on a map without being named, but still serve as adequate pin-points.

At night, villages may disappear in black-out conditions, and towns may become indistinct, but the presence of traffic, especially of trams and electric trains, that flash over the points, is sufficient to indicate a centre of population. The amount of light displayed in a town usually decreases during the night, and in peace-time this change is likely to confuse the Navigator by being very pronounced.

(v) *Roads*.—Roads are usually very difficult to identify because of their multiplicity, and because main roads may be less conspicuous than secondary roads by reason of their dark metalled surface. The modern concrete arterial road of wide proportion is easier to recognise both by day and night. Traffic at night, even in black-out conditions, will disclose the presence of a road, its importance being indicated by the volume of traffic visible.

Auto-bahns are well-defined landmarks, though camouflaging may reduce their distinctiveness. They remain about as obvious as all large highways.

(vi) *Woods*.—These are clearly marked on maps usually to represent their size and shape, and are often easy to recognise. In heavily wooded and forest country, the clearings are more important. Care must be exercised because woods may have been cut since the map was compiled.

(vii) *Golf Courses*.—These are sometimes fairly good landmarks by day, distinguishable by their bunkers and greens, and are also possible emergency landing grounds.

(viii) *Aerial Beacons*.—Where landmarks are scarce, special air beacons are sometimes constructed. These may vary, in peace time, from the familiar names painted on gas holders or inlaid on landing ground circles, to arrows and figures set up to guide the Navigator along a particular route. Aerial signposts exist on several desert air routes, notably in Africa. By night, aerial beacons flashing distinctive light characteristics are available in peace or war, since a simple expedient renders them useless to the enemy.

Seamarks

36. (i) *Coast Lines*.—These are most valuable to the Air Navigator by day and by night. While it may be difficult, if not impossible, to recognise a particular stretch of coast in any area merely from its appearance, yet by taking a bearing of its general trend or direction, a satisfactory degree of certainty may often be obtained. Thus the coast of Western Europe has most distinctive directions which cannot easily be confused; e.g. compare the Belgian coast and the coast near Amsterdam. Care should be taken not to mistake a bank of clouds for a coast line at night.

(ii) *Sandbanks, Rocks and Shoals* make excellent marks at sea and are shown on Admiralty Charts and some topographical maps. The state of the tide affects their visibility, but when covered they will appear as a discontinuity in the general colour of the sea. Surf breaking on a bar, reef or beach is clearly visible at night, but may be confused with sand which is rather less conspicuous.

A fault in the sea bed may also be clearly visible. The Hurd Deep situated off the coast of Brittany is sharply defined on calm days by a darkening of sea colour.

(iii) *Lightships*.—These usually have their names painted in large letters on the hull in peace time. In war they are anonymous.

(iv) *Large Buoys*.

(v) *Lighthouses* and conspicuous towers or buildings.

(vi) *Cliffs*.—These often have distinctive colours which assist recognition.

(vii) *Marine Lights*.—These are primarily intended for marine use, but usually afford the Air Navigator valuable assistance at night. When flying near them, the actual light will often be too low to see, but the characteristics of the light may often be told by considering the beams of light which are nearly always visible. In war, special arrangements may be made to show certain marine lights not normally lit.

(viii) *Sea Traffic*.—Ships at sea often follow definite tracks to or from port, particularly in peace time. The presence of merchant shipping usually indicates a shipping "lane," and by using his common sense a Navigator can often judge from or to which point a ship is bound. If used with discretion this may be of value when out of sight of land.

Limitations of Navigational Projections

37. Before the Air Navigator can use a map intelligently for plotting he must know something of the properties and construction of the map. Fortunately, there is only one projection eminently suitable for plotting, namely, Mercator's; and because it is the only one in which all meridians and parallels are straight lines, it can be instantly recognised.

Mercator's Projection

38. As a general rule Air Navigators find it far more convenient to follow a rhumb line track over the Earth than to save a few miles distance by following a great circle track. In any case the advantage of the latter route is generally rather small. Consider the following comparisons:—

					<i>Rhumb Line</i>	<i>Great Circle</i>	
					<i>Distance</i>	<i>Distance</i>	<i>Difference</i>
Calshot to New York	...	...	...	...	3088 n.m.	2976 n.m.	112 n.m.
„ „ Tokyo	...	...	...	...	6182 n.m.	5219 n.m.	963 n.m.

It appears that in the former case about $3\frac{1}{2}$ per cent. of the rhumb line distance is saved by following the great circle, and in the latter, about $15\frac{1}{2}$ per cent. In shorter distances, the differences are very much less.

39. Now consider a flight from an aerodrome, say, in the North of Scotland to a point 500 miles to the East, and at the same latitude as the aerodrome. The great circle track measures 083° T at first, but changes roughly at the rate of 1° every 35 miles until the track is finally 097° T. The rhumb line track would be along the parallel, that is, 090° T for the whole journey, and would only be about one mile longer. Generally speaking the saving in distance by following great circle tracks in flights up to 1,000 miles is not worth the additional trouble involved.

40. It is obviously a great help if a rhumb line can be laid down on a map by simply drawing a straight line. If it is to be a straight line, then all meridians which the rhumb line cuts on the map must be straight lines parallel to each other, so that all make the same angle with it. This arrangement of the meridians would, therefore, provide one of the Navigator's requirements.

41. The second and extremely important navigational requirement is that angles anywhere on the Earth's surface shall be correctly represented on the map. Clearly the Equator and all parallels of latitude cut all the meridians at right-angles *on the Earth*. Hence, if angles are to be shown correctly, the Equator and parallels must all cut the meridians at right-angles *on the projection*.

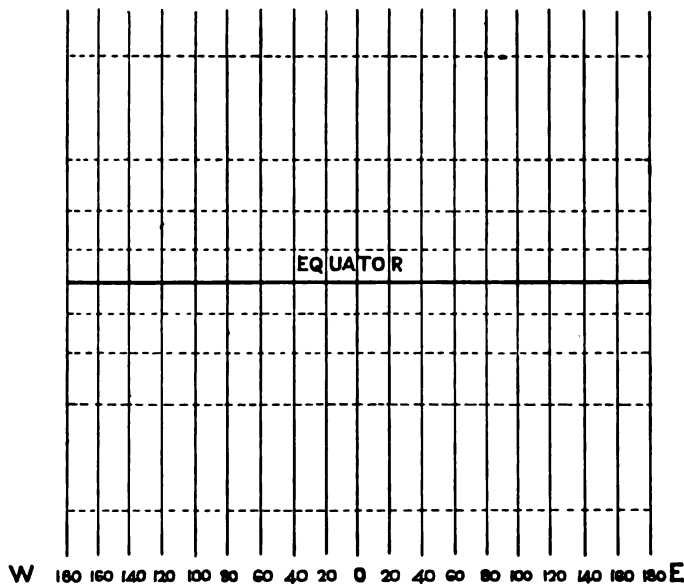


FIGURE 6. The Skeleton of Mercator's Projection.

42. So far, so good: The projection thus described begins to take form. It will first consist of parallel straight lines representing the meridians, which, by agreed practice, are drawn up and down the paper. Secondly, there will be a series of parallel straight lines, representing the parallels of latitude, running across the meridians at right-angles, and therefore horizontally across the paper. If the meridians are shown at intervals of, say, 20° of longitude, they will all be equally spaced, and the whole Earth will extend *longitudinally* between the 19 vertical lines in Figure 6. (The first and last meridians are really the same.) The Equator is also shown in Figure 6, but the parallels of latitude are only dotted, because their spacing apart has yet to be decided.

43. Now look at Figure 7, or at any globe. It will be seen that while the parallels of latitude are to all intents and purposes evenly spaced, the meridians gradually converge together and all finally meet at the Poles. Compare this state of affairs with the appearance of the meridians in Figure 6 above. If the space between the meridians in Figure 6 is true to scale at the Equator, it has certainly undergone considerable *expansion* on either side of the Equator, and this expansion of scale increases to infinity as the Poles are reached.

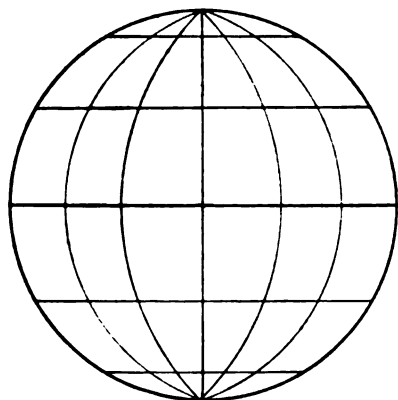


FIGURE 7.
Meridians and Parallels on a Globe.

It is easy to find a formula that accurately describes the expansion caused by this arrangement of the meridians. Referring once more to Figure 7, or to any globe, it will be seen that any two meridians are at a maximum distance apart at the Equator, that is, at latitude 0° ; whereas they are at zero distance apart at the Poles, namely at latitude 90° . It can be shown mathematically that this change of their distance apart with the angular value of latitude exactly corresponds with the trigonometrical function of any angle known as its *cosine*. In other words, it can be said that the spacing apart of meridians *on the Earth* varies as the cosine of the latitude.

44. But with the meridians arranged as in Figure 6 their spacing apart does not change at all. Suppose two meridians are 1-inch apart at the Equator. At 60° N (or S) they will still be shown as 1-inch apart; though it is known that on the Earth they are only $\frac{1}{2}$ -inch apart, for $\cos 60^\circ = \frac{1}{2}$. Obviously their spacing apart has been expanded by 2, since $\frac{1}{2}'' \times 2 = 1''$. Generally speaking, then, the rate of expansion on either side of the Equator *on the projection* varies as the reciprocal of the cosine, i.e., with the *secant of the latitude*.

45. Evidently this arrangement of the meridians represents an expansion of the scale of distance East and West except along the Equator. In order to avoid having one scale for distances measured East and West at any point and another scale for distances measured North and South from the same point, it is necessary to expand the scale of distance North and South at exactly the same rate, namely it must also vary as the secant of the latitude. This means that parallels of latitude, which on the Earth are equidistant, must be shown on the projection at greater and greater distances apart.

46. This point may perhaps best be understood if the implications of preserving correct shapes are considered.

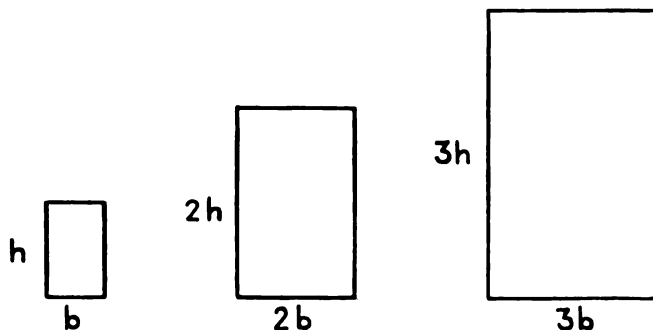


FIGURE 8. Rectangles of Identical Shape.

47. In Figure 8, three rectangles of similar shape but different size are shown. Each can be said correctly to represent the others in shape if the ratio of base to height is in every case the same. That is, for shapes to be identical, $\frac{b}{h}$ must be a constant value.

Thus in Figure 8, if the bases are b , $2b$, $3b$, the shapes will only be exactly similar if the heights are h , $2h$, $3h$ respectively, for then

$$\frac{b}{h} = \frac{2b}{2h} = \frac{3b}{3h} = \text{a Constant.}$$

Therefore in Mercator's projection, where the distance between any two meridians is expanded on either side of the Equator, the distance between successive parallels must be expanded in the same way if shapes are to be maintained.

48. Since the value of secant 90° is infinity, it will not be possible to represent the Poles, and indeed the expansion becomes so rapid above about latitude 75° that the usefulness of this projection is very reduced at such high latitudes. The distortion is well illustrated in any Atlas using Mercator's projection, where India, though in fact about four times as great in area as Greenland, actually appears to be four times smaller.

49. It is now possible to complete the projection begun in Figure 6, by drawing in the parallels of latitude. The calculations for the spacing of the parallels are embodied in *Tables of Meridional Parts*, as published in Norie's *Air Tables*, or Inman's *Tables*.

50. *Meridional parts*, sometimes called mercatorial parts (mer. parts, or m.p.) are the number of times the length of one minute of longitude on Mercator's projection is contained in the projected distance between the Equator and any particular parallel of latitude on the map.

Thus if the length of $1'$ of longitude on a Mercator's projection is, say, 0.02 inch, the distance between the Equator and, say, parallel 30° N. is

$$\begin{aligned} & 0.02'' \times \text{m.p. for } 30^\circ \\ &= 0.02 \times 1876.67 \text{ inches} \\ &= 37.5334 \text{ inches} \end{aligned}$$

A specimen graticule on Mercator's projection is given in Figure 9.

The Use of Mercator's Projection

51. The student should now be in a position to know how to use a map or chart on Mercator's projection. Its properties are summarised under the following headings:—

- (i) Scale.
- (ii) Bearings.

Scale

52. On the Earth the length of a minute of latitude is very nearly constant (see Chapter I, paragraph 56 (ii)), and consequently it affords a convenient measure of distance. On the other hand, the length of a minute of longitude on the Earth varies from being roughly equal to a minute of latitude at the Equator, to zero length at the Pole. It is thus of no value as a measure of distance.

53. On Mercator's projection these conditions are apparently, but *only* apparently, reversed, since the length of the minute of latitude increases steadily North and South of the Equator, while the minute of longitude is the same length in the map wherever it is measured. Nevertheless, the Navigator must realise that the physical scale of distance itself increases steadily North and South of the Equator on the projection. Hence it is necessary to use a measure for distance which varies in the same way, and this is provided by the latitude subdivisions themselves.

Point No. 1 is that the Air Navigator must always use the latitude subdivisions for measuring physical distances, and above all, never use the longitude subdivisions for this purpose.

54. For accurate practical plotting it is necessary to use a uniform scale for solving velocity problems. Such a scale is ready to hand in the longitude scale, each division of which is of equal length on the projection. Each unit of longitude can be called any unit of distance, speed or interval of time that best suits each problem.

Point No. 2 is that in velocity constructions the Air Navigator should not use the latitude subdivisions or plot in actual distances, because these vary in projected length. He can if it is desirable use the longitude subdivisions.

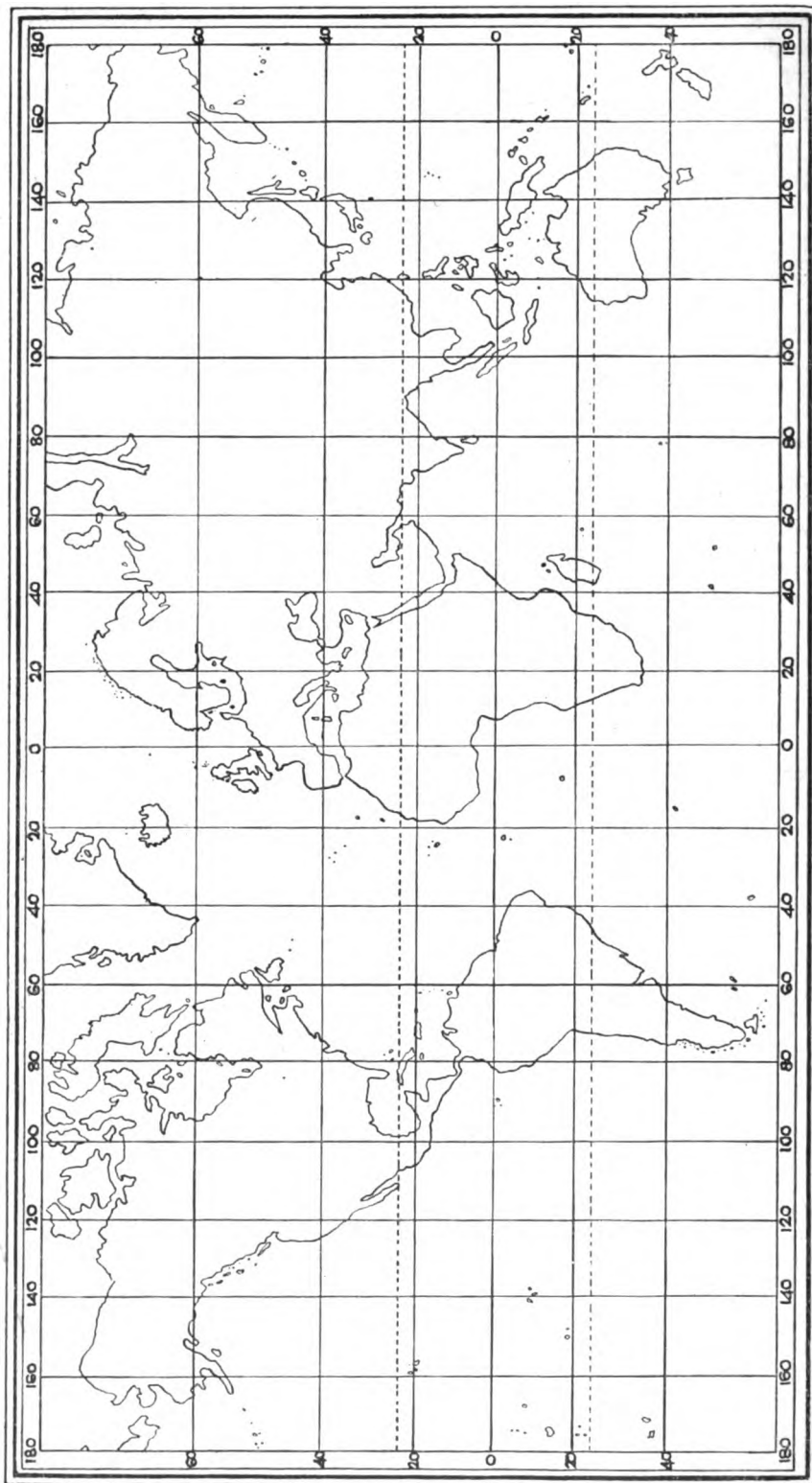


FIGURE 9. The World on Mercator's Projection.

55. Since the scale of a Mercator's projection increases with latitude, the Navigator who wishes to refer to the scale of a particular sheet should state the latitude to which this scale refers, e.g. "One/Million at 56° N."

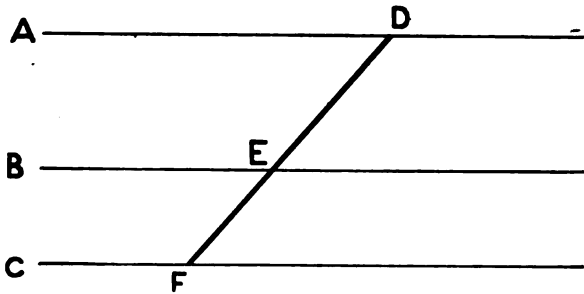


FIGURE 10. Measurement of Distance.

subdivided meridian (nautical miles) approximately between D and F, and, with this setting, step along the line DF, finally measuring any "remainder" against the latitude subdivisions on either side of B.

Or (ii) Open up the dividers to cover the length DF, and step the complete distance up the nearest subdivided meridian so as fairly evenly to overlap the latitudes of A and C. Then read the number of minutes of latitude (nautical miles) between the extended points of the dividers.

Or (iii) If the line is too long for the dividers, measure small portions such as DE and EF by either of the above methods and add them together.

57. If the distance is required in statute miles, the nautical miles so obtained may be converted as explained in Chapter I, paragraph 57. A variable scale of statute miles is also provided on the sides of the Plotting Maps (G.S.G.S. 4080—5012). This should be used in the same way as described above.

Bearings

58. On Mercator's projection all bearings measured from straight lines are rhumb line bearings and are the same no matter from what meridian the measurement is made. The drawing or measurement of rhumb line bearings on such a projection thus presents no difficulties.

59. However, a great circle cuts successive meridians at different angles, and since meridians on Mercator's projection are parallel to one another, the great circle will be represented as a curved line, convex towards the nearer Pole. The drawing or measurement of great circle bearings on Mercator's projection therefore calls for a special procedure which will now be explained. Before doing so it will be necessary to examine the relationship between the rhumb line and the great circle joining any two places on the Earth.

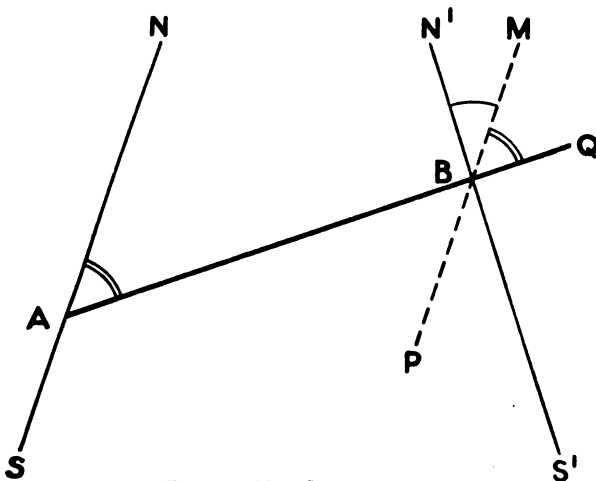


FIGURE 11. Convergence.

The Measurement of Distance

56. All straight lines on Mercator's projection are rhumb lines, though the Equator and all meridians are great circles as well. It follows that distances measured on Mercator's projection are rhumb line distances.

Suppose A, B and C are parallels of latitude and it is desired to measure the rhumb line distance DF in Figure 10.

Take a pair of dividers and either

(i) Select a convenient number of minutes of latitude from the nearest

latitude between D and F, and, with this setting, step along the line DF, finally measuring any "remainder" against the latitude subdivisions on either side of B.

Or (ii) Open up the dividers to cover the length DF, and step the complete distance up the nearest subdivided meridian so as fairly evenly to overlap the latitudes of A and C. Then read the number of minutes of latitude (nautical miles) between the extended points of the dividers.

Or (iii) If the line is too long for the dividers, measure small portions such as DE and EF by either of the above methods and add them together.

Convergence

60. The reason why a great circle cuts successive meridians at different angles is that on the Earth the meridians are not parallel but are inclined at angles to one another. The inclination between any two meridians is called their *Convergence*, and it represents the angular difference between a great circle being measured at either meridian.

Thus in Figure 11, ABQ is a great circle arc, and NS, N'S' are meridians at A and B respectively. Through B, a line MP is drawn parallel to NS.

It will be seen that the difference between angle NAB and angle N'BQ is angle N'BM, the convergence between NS and N'S'.

It has been stated above that the angles contained between the rhumb line and the great circle arc are for practical purposes equal. Let these angles be called C .

Then $BAX = ABZ = C$

Furthermore, opposite angles are equal.

$\therefore ABZ = YBQ = C$

Now $NAX = NAB + C$

Substituting in (1) above,

$N^1BY = NAB + C$ (2)

But $NAB = MBQ$ (corresponding angles)

and $MBQ = MBY + C$ (See Figure 12).

$\therefore NAB = MBY + C$

Substituting in (2) above,

$N^1BY = MBY + 2C$

But $N^1BY = MBY + N^1BM$ (See Figure 12).

$\therefore N^1BM = 2C$

In other words, the Convergency equals twice Conversion Angle, or alternatively, Conversion Angle equals half Convergency.

64. It has been seen in paragraph 61 above that for two places situated at different latitudes, the convergency is given with sufficient accuracy by the formula :—

Convergency = Ch. Long. $\times$ sin mean Lat.

Hence Conversion Angle = $\frac{1}{2}$ Ch. Long. $\times$ sin mean Lat.

Example :—

65. What is the Conversion Angle where A is a position in $35^\circ 15' S$ $10^\circ 45' E$ and B is a position in $25^\circ 45' S$ $02^\circ 15' W$?

The mean Lat. is 31° (to the nearest degree).

The Ch. Long. is $13^\circ W$

$\therefore C.A. = \frac{1}{2} \times 13^\circ \times \sin 31^\circ$

$= 6.5^\circ \times 0.51504$

$= 3^\circ$ (to nearest degree).

66. To avoid calculating Conversion Angle in the air, special facilities are provided for the Air Navigator. On the margin of all Plotting Maps (series G.S.G.S. 4080) and inside the Navigator's Log cover an "abac" is provided. The abac is accompanied by instructions for its use in each case, and it should be noted that the details of the abac are not uniform, though the principle operation is the same.

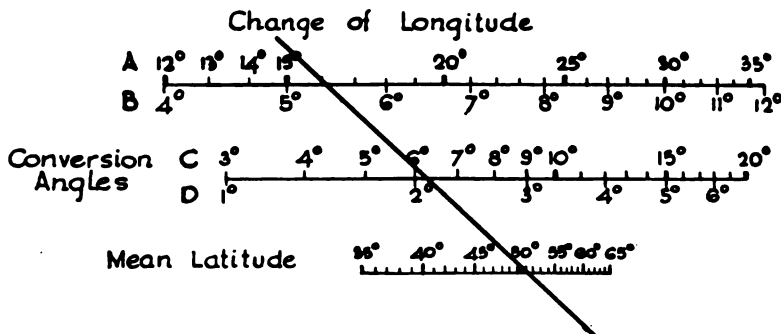


FIGURE 13. An "Abac."

67. In Figure 13 a Conversion Angle has been determined by means of an abac for two places the change of longitude between which is 16° and whose mean latitude is 51° . The Conversion Angle is a little over 6° .

68. Alternately a *Douglas Protractor* may be used as follows :—

Draw a line from the centre of the protractor out to the graduation corresponding to the mean Latitude. Mark off on this line from the centre a length equal to half the Ch. Long. (to a convenient scale) and from this draw a line perpendicular to the Zero graduation line of the Protractor. The length of this second line gives the Conversion Angle at the scale adopted. The procedure is illustrated in

Figure 14 where a Conversion Angle of 6° (length of XY to scale) is derived from the mean Latitude of 51° and a Ch. Long. of 16° . (Scale : 1° equals the length of one square.)

It is now possible to revert to the question of plotting or measuring great circle bearings on Mercator's projection.

69. Measurement of Great Circle Bearings from a Mercator's Projection :

- (i) Lay off and measure the rhumb line bearing between the two places concerned.
- (ii) Determine and apply the Conversion Angle.

Since the rhumb line between two places always lies on that side of the great circle arc nearer the Equator, it is true to say that the great circle bearings of all places in any way East of an observer in the Northern hemisphere are less than the corresponding rhumb line bearings, and vice versa. The reverse is true in the Southern hemisphere. A useful rhyme for application in the NORTHERN hemisphere is :

" All places East by great circle bear Least."

" All places West by great circle bear Best."

It is usually safest to draw a rough sketch of the situation, from which it will be obvious which way to apply the Conversion Angle to the Rhumb Line bearing.

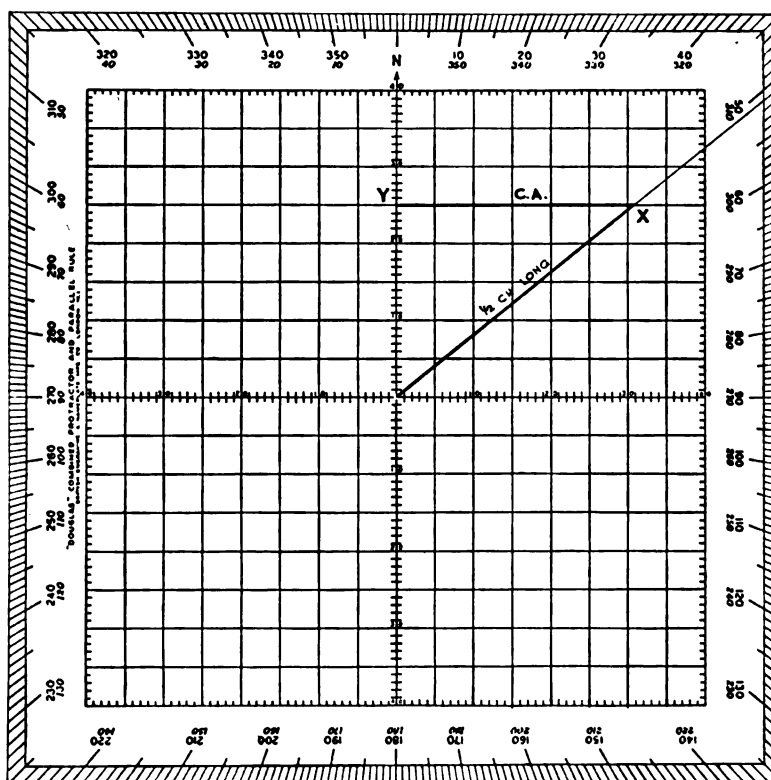


FIGURE 14. Conversion Angle by Douglas Protractor.

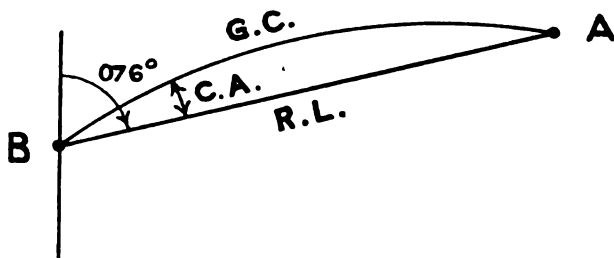


FIGURE 15.

Rough Sketch for Application of Conversion Angle.

Example :—

70. Determine the great circle bearing of A ($52^\circ 30' \text{ N } 05^\circ 40' \text{ E}$) from B ($51^\circ 30' \text{ N } 00^\circ 47' \text{ W}$) with the aid of a Mercator's projection.

By joining A to B, the rhumb line bearing of A from B is found to be 076° T .

The mean Lat. is 52° N and the Ch. Long. 6° E (to nearest degree) from which the Conversion Angle is found to be 2° (to nearest degree).

71. The situation is approximately represented by Figure 15, from which it is clear that the Conversion Angle must be *subtracted* from the rhumb line bearing to obtain the great circle bearing of A from B.

Answer : The great circle bearing of A from B is $076^{\circ} \text{ T} - 2^{\circ} = 074^{\circ} \text{ T}$.

(Note : Had the bearing of B from A been required, the conversion angle would have been *added* to the rhumb line bearing, i.e. $256^{\circ} \text{ T} + 2^{\circ} = 258^{\circ} \text{ T}$.)

Plotting a Great Circle Bearing on a Mercator's Projection

72. This problem is presented in two ways :—

- (i) Laying off the complete great circle bearing between any two places.
- (ii) Laying off only a part of the great circle bearing between two places, namely, a short arc at either of the two places.

73. The Air Navigator is seldom asked to draw the complete great circle arc between two places on a Mercator's projection. If it is necessary to do so, a Great Circle Diagram* (on a Gnomonic projection) enables the great circle arc to be laid off as a straight line between the two places. A number of intermediate points are then chosen along this line and their latitude and longitude obtained from the Great Circle Diagram. Alternatively, the latitude and longitude of selected points may be calculated as explained in A.P. 1456, Chapter XVII. These points are then transferred to the Mercator's projection, and a curved line is drawn free-hand between the two places, passing through all the intermediate points *en route*. (See Figure 16.)

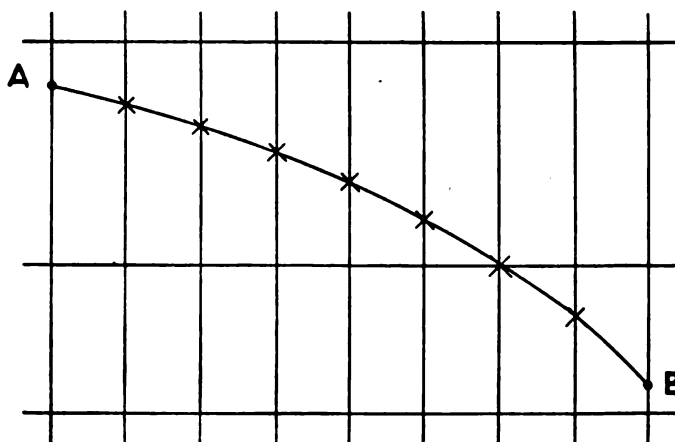


FIGURE 16. Plotting a Great Circle on Mercator's Projection.

74. Frequently the Air Navigator has to lay off on a Mercator's projection a small part of the great circle bearing between two places, as for example, when plotting the bearing of an aircraft obtained by a ground D/F station. The details of the procedure for plotting D/F bearings are explained fully in Chapter VI. For the present, it is proposed only to outline the principle involved.

75. Consider two places in known positions on a Mercator's projection. It is desired to draw a short line at either place to indicate the great circle bearing of the other.

Join both places by a straight (rhumb) line, and determine the Conversion Angle as already explained.

If a short straight line is drawn at either place in the direction of the other, and inclined towards the nearer Pole, so as to make an angle with the rhumb line equal to the Conversion Angle, such a line

*Chart No. 5029, published by the Admiralty and described in A.P. 1456, Chapter XVII.

may be considered for all practical purposes to represent a short arc of the Great Circle between the two places. (See Figure 17.)

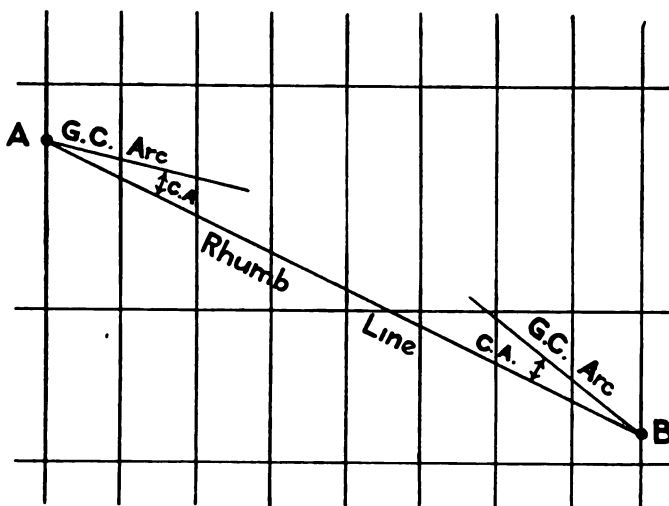


FIGURE 17. Plotting Part of a Great Circle on Mercator's Projection.

Calculation of Rhumb Line Bearing and Distance

76. Although the measurement of rhumb line bearings, tracks and distances was dismissed fairly summarily in the preceding paragraphs, it may be that the two places, between which the rhumb line bearing and distance are required, are very remote, or do not fall on the same map sheet, or indeed are not to be found on the maps which are available to the Navigator. In such an event the rhumb line bearing and distance must be calculated. There are three possibilities :—

- (i) The N-S case.
- (ii) The E-W case.
- (iii) The Intermediate case.

The N-S case

77. In the unlikely event of the two places concerned having identical longitudes, the bearing is known, since both places lie on a common meridian. Their distance apart in nautical miles corresponds to their change of latitude expressed in minutes.

Example :—

78. Express the position of A ($31^{\circ} 05' \text{ N } 30^{\circ} 20' \text{ E}$) as a bearing and distance from B, ($08^{\circ} 15' \text{ S } 30^{\circ} 20' \text{ E}$).

A is due North of B, hence the rhumb line bearing is 000° T .

$$\begin{array}{rcl} \text{Lat. A} & & 31^{\circ} 05' \text{ N} \\ \text{Lat. B} & & +08^{\circ} 15' \text{ S} \\ \hline \end{array}$$

$$\therefore \text{Ch. Lat.} = 39^{\circ} 20' \text{ N from B to A}$$

$$= 2360'$$

$$\therefore \text{the distance} = 2360 \text{ n.m.}$$

*Answer :—*A's position is $000^{\circ} \text{ B } 2360 \text{ n.m.}$

The E-W case

79. In the unlikely event of the two places concerned having the same latitude, the bearing is again known, since the rhumb line joining the two places follows the common parallel of latitude. It will be recalled (para. 43) that on the Earth the length of a minute of longitude varies with the cosine

of the latitude. Assuming that a minute of longitude at the Equator is a nautical mile in length, the distance in nautical miles between two places both situated at latitude θ° is given by the formula :

$$\text{Approx. Distance} = \text{Ch. Long. (in minutes)} \times \cos \theta^\circ.$$

Example :—

80. What is the rhumb line bearing and distance of A ($51^\circ 21' \text{ N } 03^\circ 20' \text{ W}$) from B ($51^\circ 21' \text{ N } 01^\circ 22' \text{ E}$) ?

A is due West of B, hence the rhumb line bearing is 270° T .

Long. A	$03^\circ 20' \text{ W}$	log 282	$\frac{2.45025}{1.79558}$
Long. B	$+ 01^\circ 22' \text{ E}$	log cos $51^\circ 21'$	$+ \frac{2.45025}{1.79558}$
$\therefore \text{Ch. Long.} = 04^\circ 42' \text{ W from B to A}$		$\therefore \log (282 \times \cos 51^\circ 21')$	$= 2.24583$
$= 282' \text{ W}$			
The approx. distance = $282' \times \cos 51^\circ 21'$			
$= 176 \text{ n.m.}$			

*Answer :—*A's position is $270^\circ \text{ B } 176 \text{ n.m.}$

The Intermediate case

81. When the two places have neither a common latitude nor a common longitude, the rhumb line bearing and distance between them may be calculated. The most convenient method is explained here. An alternative method is also explained in A.P. 1456, Chapter XVI.

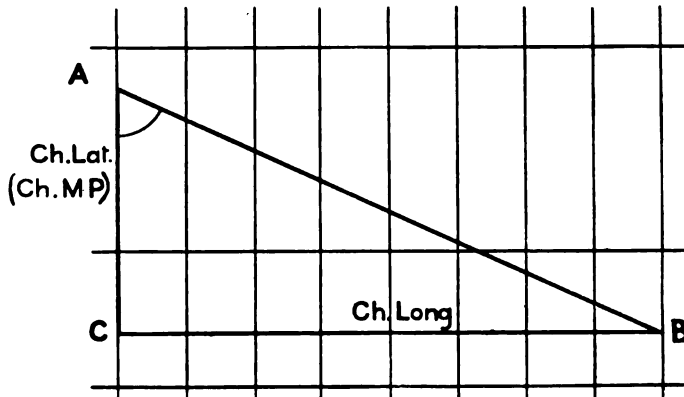


FIGURE 18. Calculating Rhumb Line Bearing and Distance.

82. Suppose it is required to calculate the rhumb line bearing and distance of B from A in Figure 18, where both are represented on a Mercator's projection.

AC in length measures the Ch. Lat. between A and B

BC in length measures the Ch. Long. between A and B.

83. Since triangle ACB is right-angled at C, it can be solved by plane trigonometry, two sides (AC and BC) being known. However, it has already been explained that though AC and BC may both be expressed in minutes of Lat. and Long. respectively, these minutes are *not comparable units of length*, for, except at the Equator, a minute of longitude is smaller than a minute of latitude. A unit of length by which *both* AC and BC can be expressed is provided by the projected length of a minute of longitude, since it is the basis for *meridional parts* by which the whole map was drawn. (See paragraph 50.)

84. Thus if BC is expressed as the change of longitude between A and B in minutes, and AC is expressed as the change of mer. parts between A and C, both BC and AC are comparable.

$$\tan \text{ angle CAB} = \frac{\text{Ch. Long. (in minutes)}}{\text{Ch. Mer. Parts.}}$$

Angle CAB can thus be readily calculated. It should be noted that the angle found will always be a number of degrees E or W of N or S. The True Bearing may be obtained by applying the angle

to 000° or 180° as appropriate. Thus in Figure 18 the bearing of B from A will be *South* so many degrees *East*, or 180° —angle CAB.

85. It is now possible to calculate the length of AB from the formula :—

$$AB = AC \times \sec \text{ angle CAB.}$$

Now if AC is expressed as minutes of *latitude*, the answer will also be in minutes of latitude, that is to say, in nautical miles, which may be converted into other units of length as required. The formulæ can be generalised as follows :—

$$\text{Tan Rhumb Line Bearing} = \frac{\text{Ch. Long.}}{\text{Ch. M.P.}}$$

$$\text{Rhumb Line distance (n.m.)} = \text{Ch. Lat.} \times \sec \text{ Bearing.}$$

Example :—

86. Find (i) the rhumb line track and (ii) the distance from Cranwell $53^\circ 02' \text{ N } 00^\circ 30' \text{ W}$ to Hinaidi, $33^\circ 17' \text{ N } 44^\circ 30' \text{ E}$.

		<i>Lat.</i>	<i>Mer. Parts</i>	<i>Long.</i>
Cranwell ...	...	$53^\circ 02' \text{ N.}$	3767.09 N.	$00^\circ 30' \text{ W.}$
Hinaidi ...	...	$33^\circ 17' \text{ N.}$	2119.83 N.	$+44^\circ 30' \text{ E.}$
$\therefore \text{Ch. Lat.} = 19^\circ 45' \text{ S.}$			$\text{Ch. M.P.} = 1647.26 \text{ S.}$	$\text{Ch. Long.} = 45^\circ 00' \text{ E.}$
,, ,, = 1185' S.				,, ,, = 2700' E.

(i) Rhumb Line Track :—

$$\begin{aligned} \log \text{ Ch. Long.} & 3.43136 \\ \log \text{ Ch. M.P.} & - 3.21676 \end{aligned}$$

$$\therefore \log \tan \text{ Track} = 0.21460$$

$$\begin{aligned} \therefore \text{Track} & = \text{S } 58^\circ 37' \text{ E, i.e., } 180^\circ - 58^\circ 37' \\ & = 121^\circ 23' \end{aligned}$$

(ii) Rhumb Line Distance :—

$$\begin{aligned} \log \text{ Ch. Lat.} & 3.07372 \\ \log \sec \text{ Track} & + 0.28336 \end{aligned}$$

$$\therefore \log \text{ Distance} = 3.35708$$

$$\therefore \text{Distance} = 2276.5 \text{ n.m.}$$

For practical purposes, the answer may be given to the nearest whole number, thus :—

Track 121° T , Distance 2277 n.m.

Provision of Maps and Charts for Air Navigation

87. The type of map required by a unit of the Royal Air Force largely depends on the nature of its duties. Aircraft of one unit may be called upon to patrol for over 3000 miles of open sea ; those of another unit may fly long distances over continents as well as over the sea ; while yet another unit may never operate except in close proximity to its base. The diverse and sometimes irreconcilable navigational requirements of the Royal Air Force are carefully considered, and a policy has been evolved to satisfy the vast majority of map users. The maps provided are primarily for the two distinct purposes which have already been described, namely, for Plotting and for Map Reading, but some are produced to cover the Intelligence requirements of the Staff. All are listed and described in the " Royal Air Force Map Catalogue."

Topographical Maps

88. Topographical Maps are provided for intelligence and map-reading, and fall into three categories according to whether the scale is large, medium or small. Cartography has gone far to produce maps most suitable for the Air Navigator, particular attention having been paid to the colour scheme, lettering and amount of detail shown. The processes involved in making such maps are necessarily varied and complicated. Each colour has to be reproduced independently. Hence only those parts of the World

of considerable strategic importance are covered by a complete range of scale. For ease of use in the air, some of the map series are available conveniently folded.

Those maps ordinarily required by the Royal Air Force are all carefully catalogued in the "Royal Air Force Map Catalogue," which is available on demand. This publication is of very great value to all who are in any way responsible for the provision and maintenance of map stocks on Stations or elsewhere.

(i) *Large Scale Maps.*

These are provided for intelligence and target identification. Details cannot, for reasons of security, be given here.

(ii) *Medium Scale Maps*

These are intended for air map-reading over the strategically important regions on the Continent, and are on two main scales, namely, One/Half Million and One/Quarter Million, the latter being especially useful for the industrial centres of the Continent, where important detail is abundant.

Great Britain is covered by an Air Edition of the Quarter-Inch Ordnance Survey (1/253,440) which, on account of its popularity and because of its close similarity in scale to the One/Quarter Million series, is widely used for training and flying over the United Kingdom, although perhaps too much detail is shown.

(iii) *Small Scale Maps*

Maps on a scale of One/Million or smaller are considered in this class, and provide a useful general picture of any large area. In the congested countries of Europe, the scale is too small for accurate pin-pointing; but where there are fewer physical features and less development, maps on a scale even as small as One/Two Million may be quite suitable. Indeed, much of Africa is only mapped on this scale, and some parts of Asia are mapped only on One/Four Million.

Navigational Charts

89. Charts designed specially for plotting are available for the whole of Europe, the Mediterranean, and in fact for nearly all areas where training or operations are carried out. They are the Geographical Section, General Staff (G.S.G.S.) Series 4080, drawn in black and white, and red and white, on Mercator's projection to a scale of One/Million at 56° N, G.S.G.S. Series 5012, also in black and white, and red and white, in Mercator's projection to a scale of One/Two million at 56° N.

90. Only few of the features of the ground are shown, principally coast-lines, lakes, rivers, large towns, marine lights, general mountain ranges and spot heights (in metres). Many broadcasting stations are marked in abbreviated form, full particulars of which are published in a booklet (A.P.1748). An *abac*, as described in paragraph 66, is printed in the margin for derivation of conversion angles. *Compass Roses* are also provided on many of the sheets, from which directions can be obtained when using a Chart Table Plotter which is a device for drawing lines in any desired direction. Magnetic Variation is recorded by means of *isogonals* (see Chapter I, paragraph 20) drawn at intervals of one degree. The plotting chart is purposely kept as free from details as possible; but as a 10-minute graticule is provided for cross reference to topographical maps, no difficulty is experienced in pin-pointing or transferring a position from the one sheet to the other. The marginal meridians and parallels are fully subdivided, and in addition there is up both sides a scale of statute miles, which may also be used for measuring distances as described in paragraph 57. Finally, a scale of Time equivalent to the Change of Longitude between Greenwich and each meridian 1° apart is printed in the top and bottom margins.

91. Apart from its obvious suitability for plotting, the G.S.G.S. series has the advantage of being extremely cheap, for its production is comparatively simple and an inexpensive grade of paper is used. It may, therefore, be consumed at the rate of one per sortie and provides a permanent record of each flight if required.

92. For training purposes the sheets of certain areas are printed on both sides of the paper, to give even more economical consumption. It should be noted that while the plotting charts for operational requirements are on a scale of One/Million and One/Two Million, at 56° N, for special training requirements a few sheets on a scale of One/Half million at 56° N have been drawn. These enable shorter training flights to be satisfactorily plotted, *but are not intended for general use.*

Publication of New Maps

93. New maps are produced from time to time and are notified in Air Ministry Orders.

Correction of Maps and Charts

94. In time of war, information affecting the correctness of detail on topographical maps and charts is necessarily published through secret and confidential channels. Thus the location of lights, defended areas, corridors, Royal Air Force aerodromes and so on is contained in secret or confidential documents, supplemented by Air Ministry signals and Confidential Orders. Additions and corrections to marine charts are notified in Admiralty Notices to Mariners, and in cases of urgency by Admiralty signals.

95. Map Officers detailed under A.M.O. A.914/1940 must maintain under lock and key fully amended master-copies of those maps and charts used by the units to which they are responsible. The Navigators may then extract information as required and mark their own maps and charts accordingly. Such corrections should be made lightly in pencil, and removed immediately after use, or when there is danger of compromising security. Actual locations should never be used, but some private code adopted such as marking all aerodromes, lights, etc., at a chosen distance and bearing (*e.g.*, 20 miles due North) from their real positions.

How to Obtain Maps

96. The provisioning of maps and charts is regulated by A.M.O. A.914/1940 as amended by A.M.Os. A.339 and A.446/1941.

The first essential is to know exactly what maps are available, and, in particular, which maps are required. This information can best be acquired by carefully consulting the Map Catalogue referred to in paragraph 87.

Having decided what maps are required, a demand is made out *using the code references* so as to avoid unnecessary clerical work and obviate errors of supply. When a map has no code reference, its full title and description should be stated. Admiralty Charts should be requisitioned separately from maps, and will only be supplied if an air map will not do; moreover, unless specifically demanded, they will be issued not amended up to date as regards marine information.

Particulars of Admiralty Charts and other hydrographic publications are given in "A Catalogue of Admiralty Charts" published annually.

97. All demands for maps and charts for all Bomber or Coastal Command units should be made by D.R.L.S. to *D. Survey (G.S.G.S.) via Hendon Hall* (as appropriate), except that all units in Northern Ireland must demand from *The Map Officer, H.Q., Royal Air Force, Belfast*. All other units and formations demand direct from *D. Survey (G.S.G.S.), Air Ministry, Whitehall, S.W.1*. Where no D.R.L.S. is available demands should be sent to *D. Survey (G.S.G.S.), Air Ministry, Whitehall, S.W.1*. Demands are prepared as follows:—

<i>Demands from</i>		<i>How Made</i>	<i>Further Action</i>
S.H.Qs., Groups and Commands	} ...	In code on Form 771 (duplicate)	} Acknowledge receipt on the duplicate F. 771, or Minute Sheet.
Air Staff	Minute Sheet	...	

98. To ensure having maps in good time, as much notice as possible should be given. Since many of the map demands are genuinely "Urgent", every effort should be made to avoid seeking priority unnecessarily, since this interrupts the normal routine of handling demands. Sympathetic consideration where justified by unforeseen circumstances will always be given to last-minute orders, which in emergency may be signalled to the proper address stating the latest time by which the maps or charts are required. By exercising foresight, many "urgent" demands can be eliminated, and it is the duty of the officer in charge of every station Map Section to keep account of the stocks of maps on hand, so as to be able to forecast his requirements.

Accounting for Maps and Charts

99. No hard and fast rules are laid down by which map stocks must be accounted for, but it is the Map Officer's responsibility to ensure that strict economy is exercised in consumption, and that his stock of maps is kept in good order, preferably in an indexed map-press. It is most desirable to have some means of checking stocks without undue delay, and perhaps the most suitable method is to use Form 101, a Tally Card on which receipts are entered, and a balance struck every time an issue is made. It should be remembered that wasted maps represent a waste not only of money but also of the time of the printing presses, already working to capacity on maps perhaps urgently required by some other Royal Air Force Unit.

CHAPTER IV

TIME

Alice was puzzled. "In our country," she remarked, "there's only one day at a time."

ALICE THROUGH THE LOOKING GLASS

The Solar System

1. The Earth rotates upon its axis, and also revolves round the Sun along a path or *orbit*, the plane of which is inclined to the Earth's axis at about $66\frac{1}{2}^{\circ}$. Each motion is evidenced by a distinctive natural occurrence: The rotation clearly results in the succession of night after day. The revolution in orbit of the Earth about the Sun is recognisable from the succession of the seasons. (See Figure 1.)

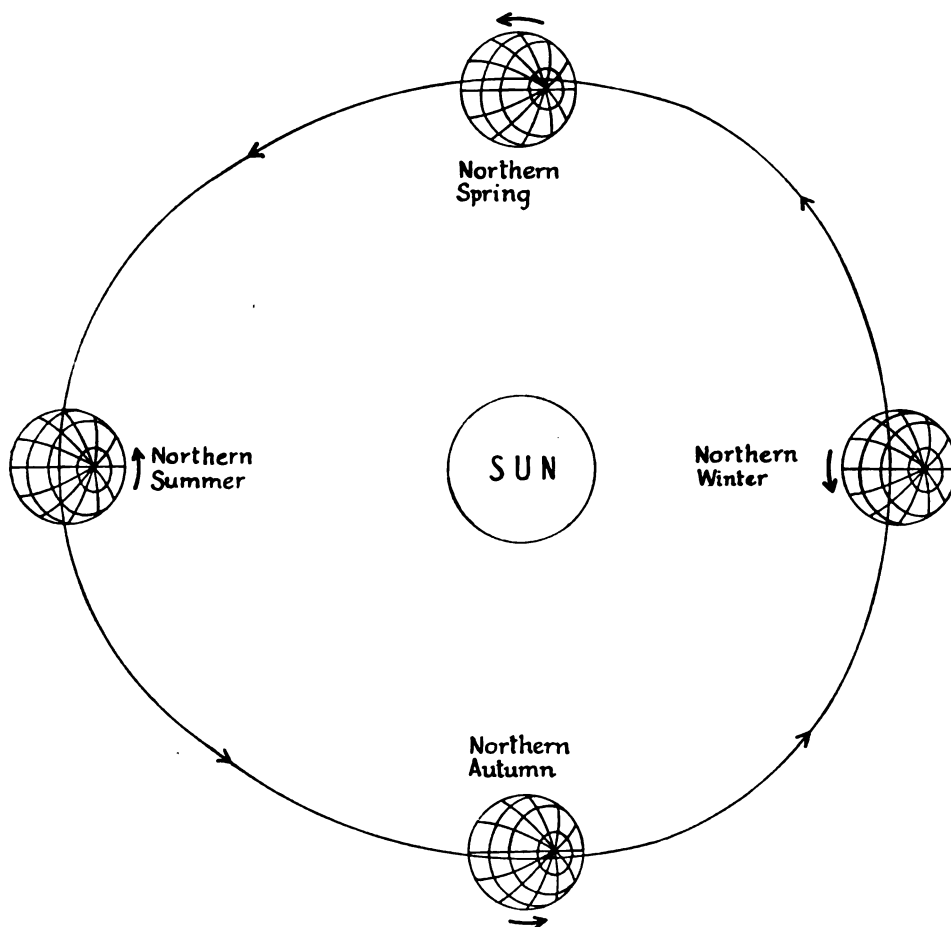


FIGURE 1. The Motions of the Earth.

2. **A Day** is the period of rotation of the Earth about its axis with special reference to either a Star, the Moon, the Sun, or even an imaginary body called the *Mean Sun*. By convention the period begins and ends when such a body crosses a meridian, and between two successive *transits*, as they are called, is a length of time known as a sidereal day, a lunar day, an apparent solar day or a mean solar day respectively. A *Civil Day* begins and ends at midnight (*lower transit*); while an *Astronomical Day* begins and ends at an *upper transit*, when a heavenly body crosses the meridian of an observer. In the case of the Sun, this is called *Noon*.

3. **A Year** is the period of revolution of the Earth about the Sun. This period may be measured with reference to the position of a star, the proximity of the Sun, the occurrence of seasons, or to an arbitrary arrangement based primarily upon the seasons; it is called a sidereal year, an anomalistic year, a tropical year or a civil year respectively.

The Measurement of Time

4. The Earth rotates at an even speed upon its axis. In order to measure the Earth's period of rotation it is necessary to observe a very distant reference point, such as a star, whose position is relatively stable. It is easier to think of the apparent movement of heavenly bodies round the Earth than to consider the real movement of the Earth beneath the heavenly bodies.

Sidereal Time

5. The interval that elapses between two consecutive passages of a star over the same meridian of the Earth may be measured. The time between two such *transits* is known as a sidereal day, and equals the period of rotation of the Earth about its axis.

Apparent (Solar) Time

6. Seen from above the North Pole, the Earth rotates at an even pace on its axis in an anti-clockwise direction, as well as revolving round the Sun on its orbit, in an anti-clockwise direction. (See Figure 1.)

7. Each of these motions separately would give an observer on the Earth the impression that the Sun was revolving round the Earth, the first causing it to go fairly rapidly from East to West, the second causing it to go slowly from West to East, completing this revolution once a year. Since both motions are operative at the same time, the Sun appears to go round the Earth from East to West.

8. The orbit of the Earth round the Sun is elliptical in shape, the Earth being nearer the Sun by about $1\frac{1}{2}$ million miles in January than in July. Yet so great is the average distance from the Sun that this proximity is not normally perceptible. The eccentricity of the orbit, however, causes the Earth to travel along it at a varying speed, fastest in January and slowest in July. To the effect this has upon the apparent speed with which the Sun travels round the Earth, must be added the effect caused by the inclination of the Earth's axis at an angle of $66\frac{1}{2}^\circ$ approximately to its solar orbit.

9. Altogether, the Sun appears to travel round the Earth from East to West at an *uneven* speed. Consequently the length of the apparent solar day, as it is called, varies throughout the year.

Mean (Solar) Time

10. It would be most inconvenient to all except primitive societies to keep apparent solar time, as the length of time between two successive transits of the Sun is continually changing. Instead, an imaginary Sun, called the *Mean Sun*, is assumed to revolve at a fixed distance round the Earth in the plane of the Equator, in exactly the same over-all time as the real Sun appears to revolve in the plane of the Earth's orbit.

11. The Mean Sun is imagined to travel at an even speed throughout the year and the interval between two successive transits of the Mean Sun is called a mean solar day.

Units of Measurement

12. The mean solar day is divided into 24 equal parts called *hours*: each hour is subdivided into 60 equal parts called *minutes*: each minute is subdivided into 60 equal parts called *seconds*.

These units are divisions of mean time. Hence the following comparison may be drawn between a mean solar day, an apparent solar day and a sidereal day:

1 mean solar day = 24 hours.

1 apparent solar day, owing to the ellipticity of the sun's orbit, apparent solar time (regulated by the sun itself) is fast or slow on apparent mean time by a variable amount between the limits of 14 minutes slow and 16 minutes fast.

1 sidereal day = 23 hours 56 minutes 4.09 seconds.

13. As a result of careful and laborious observation of the change in the relative position of the Sun and Earth, the length of a tropical year, which is the basis of the civil calendar, has been calculated as approximately 365 days 5 hours 48 minutes 46 seconds of mean time. For convenience, the civil year was arbitrarily chosen by Pope Gregory XIII in 1582, as being 365 days 5 hours 49 minutes 12 seconds

of mean time. The ordinary year is taken to be 365 days, each fourth year being called a *leap year* with 366 days. Three leap years are suppressed in every four centuries. Thus 1700, 1800, 1900 were ordinary years, while 2000 will be a leap year.

Time in Arc

14. The close relationship between a day and the rotation of the Earth about its axis has resulted in a second and perhaps more expressive system of measuring Time. The Mean Sun is assumed to travel once round the Earth every mean solar day, and therefore travels through an angle of 360° of Longitude in that time. Mean Time can be expressed in terms of Longitude and vice versa as follows :

$$\begin{aligned} 24 \text{ hours} &= 360^\circ \text{ of longitude.} \\ 1 \text{ hour} &= 15^\circ \text{ of longitude.} \\ 1 \text{ minute} &= 15' \text{ of longitude.} \\ 1 \text{ second} &= 15'' \text{ of longitude.} \end{aligned}$$

Conversly :

$$\begin{aligned} 360^\circ \text{ of longitude} &= 24 \text{ hours.} \\ 1^\circ \text{ of longitude} &= 4 \text{ minutes.} \\ 1' \text{ of longitude} &= 4 \text{ seconds.} \\ 1'' \text{ of longitude} &= \frac{1}{5} \text{th second.} \end{aligned}$$

Conversion Rules

15. When converting an angle into hours, etc., divide the degrees, minutes, and seconds in turn by 15. When converting hours, etc., into an angle, multiply the seconds, minutes and hours in turn by 15.

Conversion Tables are published in the *Air Almanac* (A.P. 1602) and *Astronomical Navigation Tables* (A.P. 1618).

Example :—

16. What difference in Time corresponds to a change of Longitude of $25^\circ 40' 30''$?

15) $25^\circ 40' 30''$ (1 hour 42 minutes 42 seconds.

$$\begin{array}{r} 15 \\ \hline 640' \\ 630 \\ \hline 630'' \\ 630 \\ \hline \end{array}$$

Example :—

17. What change of Longitude corresponds to a Time difference of 4 hours 35 minutes 20 seconds ?

$$\begin{array}{rcl} 20 \text{ seconds} \times 15 = 300'' & \div 60 = & 5' \\ 35 \text{ minutes} \times 15 = 525' & \div 60 = & 8^\circ 45' \\ 4 \text{ hours} \times 15 = 60^\circ & = & 60^\circ 00' \end{array}$$

$$\therefore 4 \text{ hours } 35 \text{ minutes } 20 \text{ seconds} = 68^\circ 50'$$

Local Mean Time (L.M.T.)

18. At any particular instant of Time, observers situated on various meridians of the Earth would experience times varying from 0 hours to 24 hours and differing from the time experienced on adjacent meridians, say, 1° apart, by 4 minutes. The Mean Time appertaining to any particular meridian is called its *Local Mean Time*.

Greenwich Mean Time (G.M.T.)

19. In order to have a Standard Time to which reference may be made at any point on the Earth, the local mean time for the Greenwich meridian is accepted internationally. Such a standard saves confusion and eliminates the necessity for duplicating large numbers of astronomical tables.

20. It has been seen that a mean solar day commences with the transit by the Mean Sun of an observer's antimeridian. The Greenwich Date (G.D.) therefore counts from the transit by the Mean Sun of the antimeridian of Greenwich. The time of transit is 00 hours 00 mins. 00 secs. G.M.T.

21. Greenwich Mean Time and Date is particularly convenient because the antimeridian of Greenwich (180° E. or W.) does not, in the main, pass through populated areas. The hypothetical change between East and West Longitude would in itself create a difficult problem for people living in close proximity to the antimeridian of Greenwich, since those living in $179^\circ 59' \text{ W.}$ might be just beginning a day which people living in $179^\circ 59' \text{ E.}$, less than 2 miles away, were just completing.

22. The L.M.T. at a place East of Greenwich is later than G.M.T. ; while at a place West of Greenwich the L.M.T. is earlier than G.M.T. The difference of time has already been shown to be simply the equivalent of change of Longitude between the place and Greenwich. It can be visualised if the position of the Mean Sun is considered, travelling from East to West round the Earth.

A rule which may be useful when converting G.M.T. to L.M.T., or vice versa, is :

" Longitude East, Greenwich Least."
" Longitude West, Greenwich Best."

24 hours are " carried over " when necessary by changing the Date.

Example :—

23. What are the G.D. and G.M.T. when the L.D. and L.M.T. at a place in Longitude $135^\circ 15'$ are April 1st, 09.00.00 hours ?

$135^\circ 15' \text{ E.}$, converted to Time = 9 hours 1 min. E.

L.D. and L.M.T. = April 1, 09.00.00

Long. in Time (E) = — 09.01.00 "*Greenwich Least*"

∴ G.D. and G.M.T. = March 31, 23.59.00

Example :—

24. What are the L.D. and L.M.T. at a place in Long. $122^\circ 45' \text{ W.}$, when the G.D. and G.M.T. are April 1, 06.00.00 hours ?

$122^\circ 45' \text{ W.}$, converted to Time = 8 hours 11 min. W.

G.D. and G.M.T. = April 1, 06.00.00

Long. in Time (W.) = — 08.11.00 "*Greenwich Best*"

∴ L.D. and L.M.T. = March 31, 21.49.00

Zone Time (Z.T.)

25. If every place kept its own Local Mean Time, confusion would result even in small countries. The time kept in neighbouring places must conform to a standard time related as nearly as possible to the changes of day and night. This is essential for the conduct of life and business. Accordingly the World is divided into 24 Zones, and, with certain exceptions, the Time kept by countries within each zone is the L.M.T. applicable to the centre of the zone.

26. The Zones consist of bands, 15° of Longitude wide, whose central meridians are spaced at intervals of 15° from Greenwich. The Greenwich meridian is the central meridian of Zone 0 which extends from $7\frac{1}{2}^\circ \text{ E.}$ to $7\frac{1}{2}^\circ \text{ W.}$ The Zones on either side are numbered consecutively 1 to 12, plus or minus according to whether they are West or East of Greenwich. The central meridian of the 12th Zone is 180° E. or W. ; hence its sign is both plus and minus. (See Figure 2.)

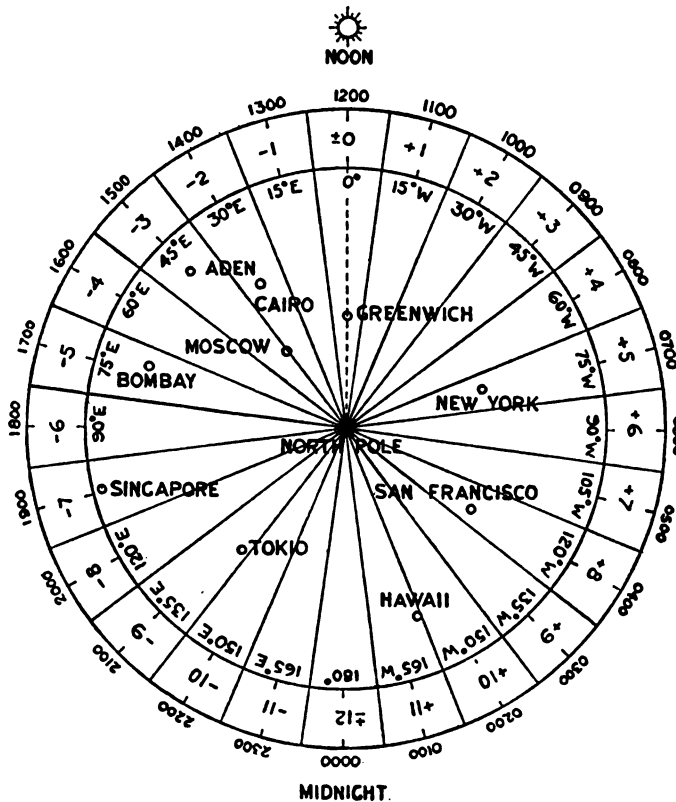


FIGURE 2. Zone Times at 12.00 hours G.M.T.

27. All places in a Zone keep the same Time, namely, the L.M.T. of the central meridian. *It follows that the L.M.T. of any place within a zone cannot differ by more than 30 minutes from the Zone Time, for the total width is only 1 hour in Time.*

28. Since all Zone Times differ from G.M.T. by whole numbers of hours, the G.M.T. may be rapidly deduced if the Zone Time and Zone Number are both known :—By applying the Zone number (and Sign) to the Zone Time, the G.M.T. is obtained.

To calculate the Zone Number and Sign

29. (i) The Zone Number is the nearest whole number of hours of the Longitude converted to Time (see paragraph 14).
 (ii) For East Longitude, the sign is MINUS.
 For West Longitude, the sign is PLUS.

Example :—

30. In what Zone is a place whose Longitude is $138^{\circ} 30' \text{ E}$?
 $138^{\circ} 30' \text{ E Longitude} = 9 \text{ hours } 14 \text{ minutes E.}$
 The place is therefore in Zone “ -9 ”.

Example :—

31. What are the limiting meridians of Zone $+6$?
 The central meridian is $15^{\circ} \times 6 \text{ W} = 90^{\circ} \text{ W}$.
 The limits are therefore $90^{\circ} \text{ W} \pm 7\frac{1}{2}^{\circ}$, namely, $82\frac{1}{2}^{\circ} \text{ W}$ and $97\frac{1}{2}^{\circ} \text{ W}$.

To Convert Z.D. and Z.T. to G.D. G.M.T., and vice versa

32. Apply Zone Number and Sign to Zone Time. (*Reverse the sign in the opposite case.*)
A useful rhyme is—

*"Longitude West, Greenwich Best
Longitude East, Greenwich Least".*

24 hours are "carried over" when necessary by changing the Date.

Example :—

33. What are the G.D. and G.M.T. when the Z.D. and Z.T. are April 1, 18.30.45 hours at a place in Zone + 8?

$$\begin{array}{rcl}
 \text{Z.D. and Z.T.} & = & \text{April 1, 18.30.45} \\
 \text{Zone (+ 8)} & = & + \quad 08.00.00 \quad \text{"Greenwich Best"} \\
 \hline
 \therefore \text{G.D. and G.M.T.} & = & \text{April 2, 02.30.45}
 \end{array}$$

Example :—

34. If the G.D. and G.M.T. are April 1, 05.30.15 hours, what are the Z.D. and Z.T. at a place in Zone + 8?

$$\begin{array}{rcl}
 \text{G.D. and G.M.T.} & = & \text{April 1, 05.30.15} \\
 \text{Zone (+ 8)} & = & - \quad 08.00.00 \quad \text{"Greenwich Best"} \\
 \hline
 \therefore \text{Z.D. and Z.T.} & = & \text{March 31, 21.30.15}
 \end{array}$$

To Convert Z.D. and Z.T. to L.D. and L.M.T., and vice versa

35. Convert the Ch. Long. between the place and the central meridian of its Zone to a Time Difference, and apply to the given Time. Remember that Z.T. and L.M.T. never differ by more than 30 minutes.

Example :—

36. What are the Z.D. and Z.T. at a place in Long. $18^{\circ} 23' W$, when the L.D. and L.M.T. are April 1, 17.28.00 hours?

By inspection the Zone is seen to be + 1, whose central meridian is $15^{\circ} W$.

$$\begin{array}{rcl}
 \text{Long. of Place} & = & 18^{\circ} 23' W \\
 \text{Long. of Zone} & = & 15^{\circ} 00' W \\
 \hline
 \therefore \text{Ch. Long.} & = & 3^{\circ} 23' E \text{ from the place to the Zone central meridian.} \\
 & = & 13 \text{ min. } 32 \text{ secs. E (in Time)} \\
 \text{L.D. and L.M.T.} & = & \text{April 1, 17.28.00} \\
 \text{Ch. Long. in Time (E)} & = & + \quad 00.13.32 \\
 \hline
 \therefore \text{Z.D. and Z.T.} & = & \text{April 1, 17.41.32}
 \end{array}$$

Example :—

37. What are the L.D. and L.M.T. at a place in Long. $115^{\circ} 43' E$, when the Z.D. and Z.T. are April 1, 18.33.20 hours?

Long. $115^{\circ} 43' E = 7 \text{ hours } 42 \text{ min. } 52 \text{ sec. E in Time.}$

Hence the Zone is, by inspection. — 8.

The Time Difference between Z.T. and L.M.T. can also be seen by inspection to be 8 hours—7 hours 42 min. 52 sec., i.e., L.M.T. is 17 min. 8 sec. less than Z.T.

$$\begin{array}{rcl}
 \text{Z.D. and Z.T.} & = & \text{April 1, 18.33.20} \\
 \text{Time difference} & = & - \quad 00.17.08 \\
 \hline
 \therefore \text{L.D. and L.M.T.} & = & \text{April 1, 18.16.12}
 \end{array}$$

Special Standard Time

38. Zone Time is kept by ships at sea, and usually countries keep that Time applicable to the Zone in which they are mostly situated. Within some political boundaries, however, a standard other than the Zone Time is adopted. Thus in peace time during the summer months the United Kingdom keeps British Summer Time (B.S.T.) one hour ahead of the Zone Time (which is of course G.M.T. in Zone O). By this means the majority of people, generally late risers, benefit by the longer daylight hours. This expedient is also used in other civilized countries, and may be modified by such considerations as war. Thus, in the present war, during the summer months B.S.T. is two hours ahead of Zone Time (G.M.T. in Zone O).

39. Confusion may easily arise when the civil population keeps a special standard time of this nature, while the theatre of operations of the Services is World-wide. When making astronomical observations, Air Navigators record times in G.M.T. (*see* Chapter VII), and to avoid unnecessary complications they are strongly urged on ALL OCCASIONS TO CONDUCT THEIR NAVIGATION IN G.M.T.

Rising and Setting of the Sun and Moon

40. A knowledge of the times of rising and setting of the Sun and Moon is often of great value in planning a flight. The *Air Almanac* (A.P. 1602) published quarterly in advance, gives such predictions as are required by the Air Navigator.

The times tabulated are in L.M.T. for the respective visible phenomena as observed from places on the Greenwich meridian.

Sunrise and Sunset

41. If there were no refraction, sunrise and sunset would occur when the centre of the Sun was horizontal to an observer at sea level. Owing to refraction, the centre of the Sun appears well above the *visible* horizon at these times, and the visible phenomena occur when the Sun's centre is really about 1° below the horizontal. The *Air Almanac* gives the times for the *visible* phenomena.

Twilight

42. The *beginning* of morning twilight and the *end* of evening twilight are tabulated, to give some indication of the amount of light that is available before sunrise and after sunset, through reflection and scattering by the atmosphere. Twilight has three phases which are explained in the following table. The Air Navigator is only concerned with the duration of Civil Twilight during which it is possible to work without artificial light, and to see other aircraft or be seen without difficulty while it is yet impossible to see many stars.

Phenomenon Begins (a.m.) Ends (p.m.)	Depression of Sun.	Remarks.
Sunrise, Sunset 	1°	Sun is just visible.
Civil Twilight 	6°	Sea horizon can be clearly seen. Work is possible without artificial light.
Nautical Twilight 	12°	Sea horizon cannot be clearly seen. Artificial Light is necessary.
Astronomical Twilight 	18°	Absolute darkness is experienced when the Sun's depression is more than 18°.

43. Because the limits of twilight are dependent upon the depression of the Sun below the horizontal, the actual duration of twilight depends upon the rate of angular movement of the Sun perpendicular to the horizontal. In the tropics this is always faster than in higher latitudes where the Sun's apparent path is inclined to the horizontal, and consequently twilight lasts only about half-an-hour. In high Latitudes the Sun's depression below the horizontal during the summer may not be more than, say, 5° all night. Civil Twilight is then experienced all night.

Moonrise and Moonset

44. The times tabulated for the visible phenomena are in L.M.T. for places on the Greenwich meridian. Since the period between successive moonrises or moonsets always exceeds 24 hours, it follows that on some days the Moon will not rise at all, and on others it will not set. Suppose the Moon rises at 23.45 hours on one day. It will not rise again for about 24 hours 45 minutes, i.e., at 00.30 hours on the *next day but one*. Such occasions are shown by heavy bracketed figures in the *Air Almanac*.

45. It will be seen that on April 1st, 1941, in Lat. 62° N on the Greenwich meridian, the moonrise is at 07.10 hours. There is no moonset until after midnight, the time tabulated in brackets being the time of moonset on March 31st. Thus, while the moon is visible on the night March 31st/April 1st, up to about 1 hour before midnight, it does not *set* at all on April 1st at that Latitude. (See Figure 3.)

Sunrise, Sunset, and Twilight at Any Place

46. Owing to the fact that the time of sunrise, sunset, or twilight at any place changes by only a minute or so from day to day, the tabulated L.M.T. for these occurrences at places on the Greenwich meridian may be taken as the approximate L.M.T. for *all* places on the Earth at similar Latitudes. Interpolation may be necessary as between tabulated Latitudes. Extracts from the *Air Almanac* for April 1st, 1941, are given at the end of Chapter VII for working all the following examples.

Example :—

47. What is the L.M.T., the G.D. and G.M.T., and the Z.D. and Z.T. of sunrise on L.D. April 1st, 1941, at a place in 32° N 33° E ?

From the *Air Almanac*, sunrise on the Greenwich meridian on G.D. April 1st, 1941, is found to be

at 05.50 hours in latitude 30° N.
and at 05.48 hours in latitude 35° N.

$\therefore$ In Ch. Lat. 5° N the change of Time is $- 2$ mins.

Hence in Ch. Lat. 2° N the change is $-\frac{2 \times 2}{5} = -1$ min. approx.

Thus, at 32° N on the Greenwich meridian the sunrise is at $05.50 - 1 \text{ min.} = 05.49$ hours.

However, this is also the L.M.T. of sunrise on *any* meridian. In position 32° N 33° E, the sunrise is therefore at 05.49 hours, L.M.T.

Long. 33° E	=	2 hours 12 min. E.
L.D. and L.M.T.	=	April 1, 05.49
Long. in Time (E)	=	— 02.12 "Greenwich Least"
$\therefore$ G.D. and G.M.T.	=	April 1, 03.37
Zone ($- 2$)	=	+ 02.00 "Greenwich Least"
$\therefore$ Z.D. and Z.T.	=	April 1, 05.37

Moonrise and Moonset at Any Place

48. The rapid movement of the Moon round the Earth as compared with the Earth's rotation under the Sun causes difficulties when calculating the time of moonrise or moonset for places NOT on the Greenwich meridian.

Owing to the revolution of the Moon in the same direction as the rotation of the Earth, the Earth has to spin through appreciably more than 360° between two successive moonrises or moonsets. There is always therefore a time-lag in phenomena connected with the Moon. (Angle G_1OG_2 in Figure 3.)

The difference between the L.M.T. of moonrise or moonset on one day, and the L.M.T. of the same occurrence on the next, or preceding day, varies, and is sometimes more than one hour.

The L.M.T. of moonrise and moonset is tabulated for various Latitudes on the Greenwich meridian.

49. Look at Figure 3 which represents the case diagrammatically as seen from over the North Pole.

O is the centre of the Earth.

G_1, G_2 are positions of the Greenwich meridian in latitude 62° N at the time of two successive moonsets.

M_1, M_2 are positions of the Moon at 23.02 hours on March, 31st 1941, and at 00.06 hours on April 2nd, 1941, respectively.

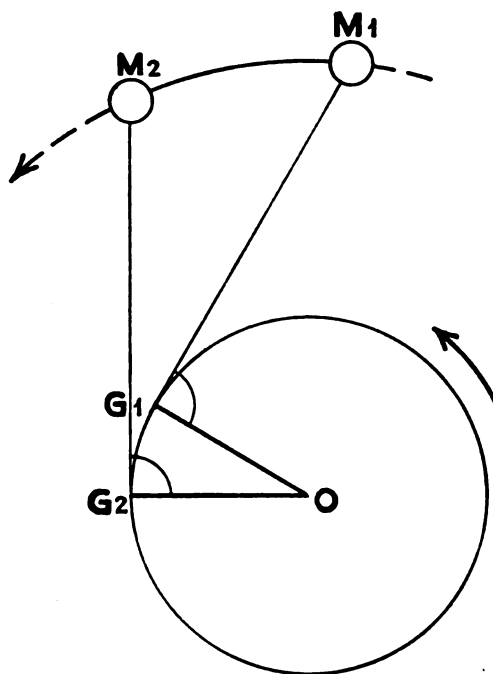


FIGURE 3. Moonset at 62° N on March 31st, 1941 (G_1) and on April 2nd, 1941 (G_2).

50. While the Earth rotates for 24 hours, the Greenwich meridian moves (anti-clockwise from above the North Pole) approximately from G_1 to G_2 again. The Moon moves in the same direction and is no longer at M_1 . Thus there is no moonset on April 1st at 23.02 hours, and the Earth has to turn an additional angle G_1OG_2 before the Moon sets on April 2nd at 00.06 hours.

51. The L.D. and L.M.T. of moonrise and moonset at places E or W of Greenwich differ from the dates and times tabulated in the *Air Almanac* by a proportion of the daily "lag" concerned. The *Air Almanac* provides a rapid and sufficiently accurate means of correcting the tabulated times by providing a table of "Differences" (approximately half the daily "lag").

52. The correction is applied direct to the tabulated L.M.T. of the phenomenon on the meridian of Greenwich to obtain the L.M.T. on the observer's meridian. The "lag" is progressive: Therefore at places East of Greenwich the phenomenon will occur at an *earlier* L.M.T. than at Greenwich and the Correction is *subtracted*. At places West of Greenwich, it will be at a *later* L.M.T. than at Greenwich and the Correction is *added*.

The rule is :

*Add, if the longitude is West,
Subtract, if the longitude is East.*

The extract from the *Air Almanac* at the end of Chapter VII is used in the following examples :

Example :—

53. What is the L.M.T., the G.D. and G.M.T., and the Z.D. and Z.T. of moonrise at a place whose position is $51^\circ 30' N$ $10^\circ 15' E$ on Local Date April 1st, 1941 ?

The L.M.T. of moonrise on the Greenwich meridian is

08.00 hours in latitude $50^\circ N$;
and 07.54 hours in latitude $52^\circ N$.

$\therefore$ In a Ch. Lat. of $2^\circ N$, the change in Time is — 6 minutes.

Hence in a Ch. Lat. of $11\frac{1}{2}^\circ$, the change will be $\frac{6 \times 3}{2 \times 2}$ min., i.e., — 4 min. 30 sec.

Hence the L.M.T. of moonrise on the Greenwich meridian at $51^\circ 30' \text{ N}$ is 08.00.00 — 4 min. 30 sec., i.e. 07.55.30 hours.

While noting these figures, extract the *Difference*, which can be interpolated by eye as 17.

Enter the Interpolation Table with this *Difference*, and the Longitude (nearest degree) and extract the proportion of the daily "lag" that is applicable as a correction, namely, 1 minute. In so doing the following fraction has been solved approximately :—

$$\frac{10^\circ 15'}{360^\circ} \text{ of the daily "lag."}$$

Now the L.D. and L.M.T. of moonrise = April 1, 07.55.30 on the Greenwich meridian

Correction for Long. (E) = — 00.01.00

∴ L.D. and L.M.T. of moonrise = April 1, 07.54.30 at the Place.

This can be converted in the usual way to G.D. and G.M.T., and Z.D. and Z.T., as follows :—

L.D. and L.M.T. = April 1, 07.54.30
Long. in Time (E) = — 00.41.00 "Greenwich Least"

∴ G.D. and G.M.T. = April 1, 07.13.30
Apply Zone (— 1) = + 01.00.00 "Greenwich Least"

∴ Z.D. and Z.T. = April 1, 08.13.30

Example :—

54. What is the L.M.T., G.D. and G.M.T., and Z.D. and Z.T. of moonset at a place in $30^\circ \text{ S } 68^\circ \text{ W}$ on Local Date April 1st, 1941 ?

The L.M.T. of moonset on the Greenwich meridian at 30° S is 21.02 hours, and the *Difference* is 22.

From the Interpolation Table the correction applicable for a Long. of 68° and a *Difference* of 22 is extracted by eye as 8 minutes.

L.D. and L.M.T. of moonset = April 1, 21.02 on the Greenwich meridian.
Correction for Long. (W) = + 00.08

∴ L.D. and L.M.T. of moonset = April 1, 21.10 at the Place.

This can be converted in the usual way to G.D. and G.M.T., and Z.D. and Z.T., thus :—

L.D. and L.M.T. = April 1, 21.10
Long. in Time (W) = + 04.32 "Greenwich Best"

∴ G.D. and G.M.T. of moonset = April 2, 01.42
Apply Zone (+5) = — 0.500 "Greenwich Best"

∴ Z.D. and Z.T. of moonset = April 1, 20.42

The Effect of Height upon Times of Sunrise, Moonrise, Twilight, etc.

55. When an observer is at a height above sea level, his visible horizon is extended. In other words, the Sun and Moon may still be visible to such an observer when they are actually some distance below the horizon visible to an observer at sea level. To this angle of *Dip* (see Chapter VII) must be added the angular value of the refraction to which a ray from the Sun or Moon is subjected as it travels *upwards* from the horizon to the observer.

56. For any particular height, the value of the *Dip* of the visible horizon, and the value of the additional refraction is known. It is therefore possible to calculate the depression of the Sun or Moon below the horizon visible from sea level, at which they may still be seen.

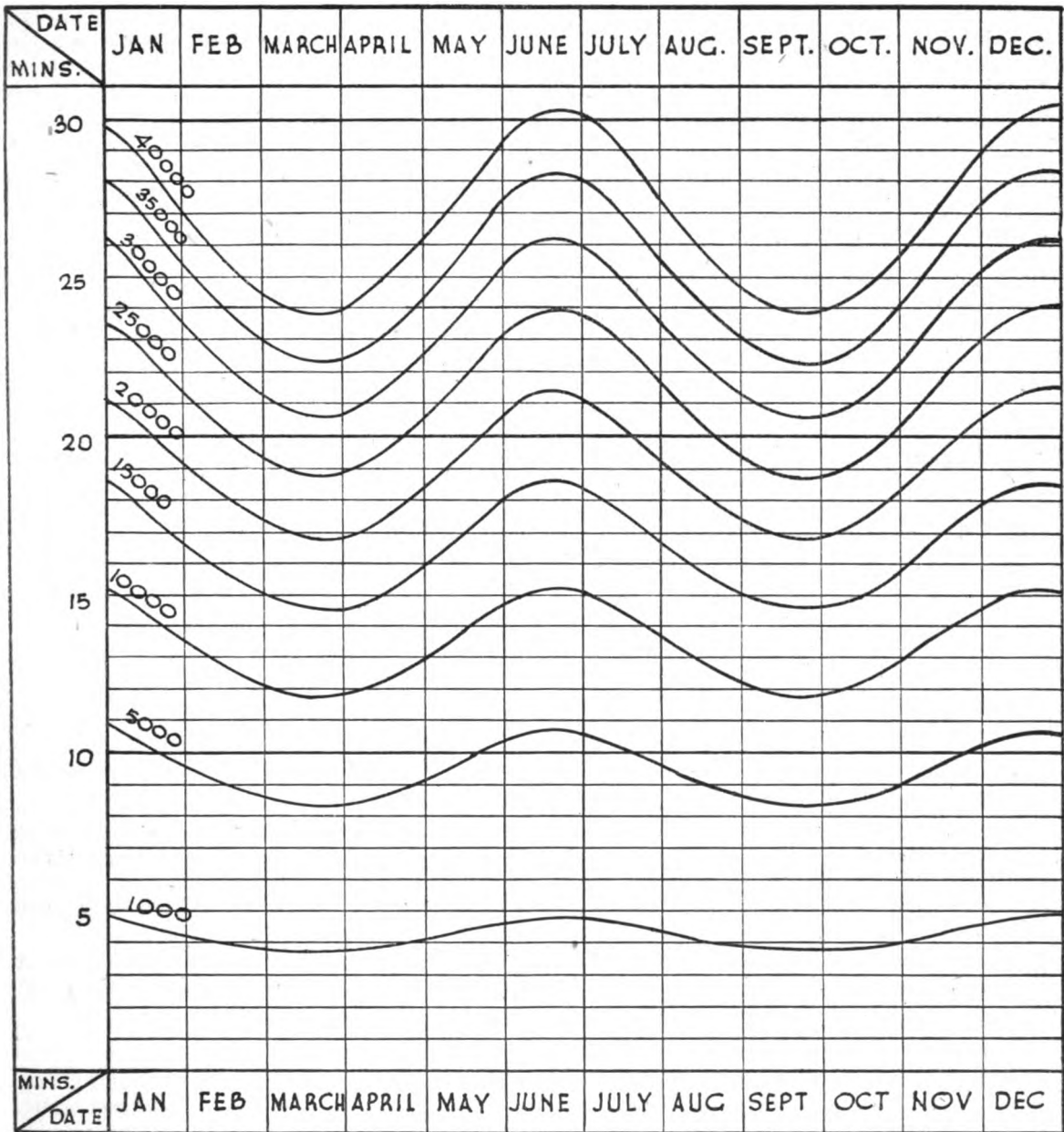


FIGURE 4. Extension in Minutes of Duration of Sunlight by Increasing Height in Latitude 50° N.

57. The rate at which the Sun moves through any given angle of depression varies continually. It will be fastest when its path is perpendicular to the horizon in late March and late September and slowest when its path is most inclined to the horizon, in late June and late December. The time taken by the Sun to move through any given angle of depression will of course vary with this rate. These times have been calculated at Latitude 50° N for various heights above the ground, and are embodied in Figure 4. They are also given in the *Air Almanac* for different Latitudes.

58. At any height above sea level, the Sun rises *earlier* and sets *later* than at sea level. To find the correction to be subtracted or added as the case may be, to sunrise or sunset, enter Figure 4 with the given height and the date, and follow across to read off the minutes of correction on the side.

59. The extension of twilight by increasing height is very much less marked, because there is a great reduction in the reflective properties of the atmosphere with an increase in height. It is therefore of little practical concern to the Air Navigator. In fact the above considerations are of most importance to the Air Staff who might require at least the cover of twilight for an operation or might wish to ensure that aircraft do not present sun-lit targets to anti-aircraft defences on the ground.

60. Since the Moon changes position very rapidly in relation to the Earth, its rate of movement through a given angle of depression varies very considerably over short periods. It is therefore not practicable to construct similar graphs for the time correction for moonrise or moonset though Height similarly prolongs the duration of moonlight.

Sunrise, Sunset, Moonrise or Moonset during Flight

61. When planning a long flight, it may be useful to know when and where to expect the Sun or Moon to rise or set. If it were simply a question of arriving at some destination, say before sunset, the time to leave could best be calculated by working backwards from the destination to the starting point.

Example :—

62. Suppose a flight of 4 hours' duration must be completed by sunset, which occurs at 17.00 hours L.M.T. at a position in Longitude 33° E., and the starting point is in Longitude 48° E. What is the latest time of departure in L.M.T.?

To avoid confusion, the calculations should be made in G.M.T. as follows :—

Sunset at destination	=	17.00 L.M.T.
Long. in Time (33° E)	=	— 02.12 "Greenwich Least"
$\therefore$ Sunset at destination	=	14.48 G.M.T.
Apply the duration of the flight	=	— 04.00
$\therefore$ Time of Departure	=	10.48 G.M.T.
Long. in Time (48° E)	=	+ 03.12 "Greenwich Least"
$\therefore$ Time of Departure	=	14.00 L.M.T.

63. When the phenomenon in question is expected to occur during the flight, the following procedure is recommended as giving suitably accurate results for all practical purposes. Greater refinements are of academic interest only, since the chief factor in determining an accurate answer, namely, the track and ground speed expressed as a rate of change of Longitude, would never be known accurately a long time in advance.

Thus, if it is required to calculate when and where the Sun or Moon will rise or set during a flight, assume an average ground speed, and find by trial and error where, on the proposed track, the aircraft will be about the time of the given phenomenon.

Example :—

64. An aircraft flying from Bermuda (32° N, 65° W) to Calshot is due to start at 19.00 hours G.M.T. on April 1, 1941, G.D. If the ground speed is expected to be 180 k, when and where will sunset occur?

From the *Air Almanac* the G.M.T. of Sunset is approximately 22.39 hours in the Latitude of Bermuda. The aircraft will therefore leave 3 hours 39 minutes before sunset at Bermuda; however, since it is flying East the sunset will approach more rapidly, and there will be less than 3 hours 39 minutes' flying before experiencing sunset. Suppose the aircraft's position after $2\frac{1}{2}$ hours' flying is calculated: This will be 450 n.m. from Bermuda, i.e., approximately in position 35° N 56° W, at 21.30 hours G.M.T.

The G.M.T. of sunset at this position, calculated from the *Air Almanac*, is 22.05 hours. Hence the aircraft is there 35 minutes before local sunset.

Again, after $3\frac{1}{2}$ hours' flying, the aircraft will have travelled a total of 630 n.m. from Bermuda and will be in approximate position 36° N 53° W at 22.30 hours G.M.T.

The G.M.T. of Sunset at this position is found from the *Air Almanac* to be 21.54 hours. Hence the Sun will have set 36 minutes before the aircraft arrives there.

An inspection of the two trial positions prompts the view that the sunset will probably occur about half-way between them, that is after 3 hours' flying. This can quickly be verified, as follows :—

At 22.00 hours G.M.T. the aircraft will be about 540 n.m. from Bermuda, i.e., in position 36° N 54° W approximately.

The sunset occurs at this position at 21.58 hours G.M.T. (from the *Air Almanac*). The difference of 2 minutes may well be off-set by irregularities of ground speed.

Keeping Time

65. The Air Navigator must be provided with a reliable watch that keeps time within a few seconds from day to day. Such watches are expensive, and during war are difficult to obtain. They should, therefore, be handled with the greatest care on all occasions.

In order to give a watch every chance of being accurate it should be kept as free as possible from harmful vibration. It is important to wind a watch steadily and at about the same time each day. To avoid confusion, Air Navigators are strongly recommended to set their watches to G.M.T.

Checking Watches

66. There are numerous convenient Time Signals broadcast daily and familiar to everybody. The Air Navigator will find these valuable when checking the performance of his own particular navigational watch. In carrying out such checks he should aim at finding :—

- (i) Whether the watch is Fast or Slow, and if so, by how much.
- (ii) What change, if any, has occurred in the accuracy of the watch since the last check.

From this information he can *rate* his watch.

Rating

67. This implies determining how much a watch either gains or loses over a given period. A carefully-rated watch is invaluable when making astronomical observations some hours after the absolute accuracy of the watch has been checked, for the Air Navigator can deduce how this accuracy has been affected in the intervening period.

Example :—

68. A watch is known to lose 12 seconds a day. At 20.00 hours G.M.T. a Time Signal indicated that it was 25 seconds Fast. What is its accuracy when used for a Moon sight at 23.30 hours G.M.T. ?

The rate is $\frac{12}{24}$ seconds lost, per hour, i.e., 0.5 second per hour. In 3 hours 30 minutes, the watch will have lost $0.5 \times 3.5 = 2$ seconds (approx.).

Thus at 23.30 hours G.M.T. the watch will be 23 seconds Fast.

CHAPTER V

THE THEORY OF D.R. NAVIGATION

*" Yes, that's about the right distance—but then I wonder
what Latitude or Longitude I've got to ? "*

ALICE IN WONDERLAND.

The Analysis of Flight Progress

1. If an aircraft were flying through still air, its passage over the Earth would be the same as its movement through the air. In other words its *Track* and *Ground Speed* would be identical with its *Course* and *True Airspeed*. As, however, the air in which an aircraft flies also moves over the Earth, the progress of the aircraft across the Earth will not usually be the same as its velocity through the air. In fact, the Track and Ground Speed is the resultant velocity of two component velocities, namely, the Course and True Airspeed and the Wind Velocity.

2. It has already been seen (Chapter II, paragraph 28) that a *resultant* velocity may be conveniently represented as a vectorial *addition* of its *component* velocities. Thus, if an aircraft is flying on a Course of 305° T at 240 k, and the Wind affecting the aircraft is $038^\circ/32$ k, the Track and Ground Speed of the aircraft will be 297° T and 244 k respectively.

3. The triangle of velocities involved may be drawn to scale as in Figure 1, where AB represents the Course and True Airspeed, BC the Wind Velocity and AC the Track and Ground Speed.

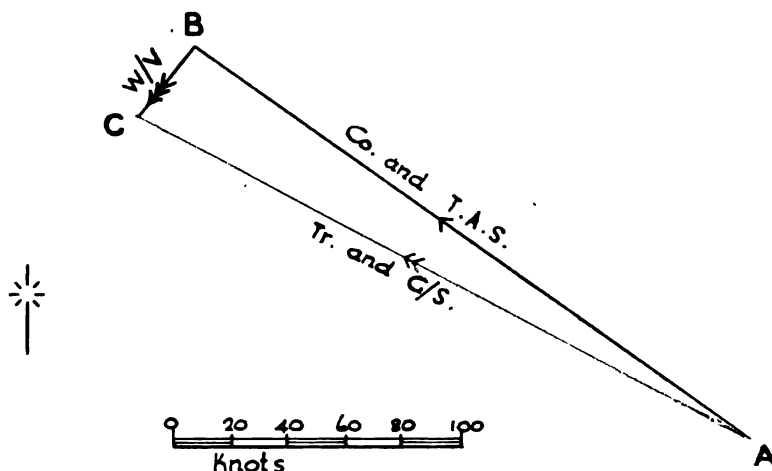


FIGURE 1. The Effect of Wind Velocity on Course and True Airspeed.

The Six Variables

4. It should be clear from a consideration of triangle ABC that in the case of all flight in an aircraft there are six variable factors, each of which has its effect upon the other five. Each side of the triangle represents in *length* and *direction* a velocity. If the length or direction of one is altered, the length and/or directions of the others may be affected.

The six factors which may vary in flight are :—

- | | | |
|-----------------------|---------------------------------------|----------------------------|
| (i) Course. | } Commonly called
"Wind Velocity". | } Component
Velocities. |
| (ii) True Airspeed. | | |
| (iii) Wind Direction. | | |
| (iv) Wind Speed. | | |
| (v) Track. | } The Resultant Velocity. | |
| (vi) Ground Speed. | | |

5. It should be borne in mind that the knowledge of *any four factors* enables the Navigator to determine the two remaining unknown. (See Chapter II, paragraph 38.)

6. The angles of triangle ABC in Figure 1 are themselves as significant as the lengths of the sides of the triangle. When alluding to the direction of the sides, reference has frequently been made to the angle each makes with the meridian (i.e., True direction). If, however, the True direction of only one side and the angles included between the other sides were known, the True direction of all sides could be deduced.

The Significance of Drift

7. In practice, much use is made of the angles included between the sides of the triangle of velocities, especially in the case of the angle of *Drift*.

Drift is the angle between the Course of an aircraft and its Track. It is measured in degrees to Port (P) or Starboard (S) from the aircraft's head.

In Figure 2, an angle of 10° drift to Port is illustrated. The aircraft's Course is 280° T and its Track is 270° T.

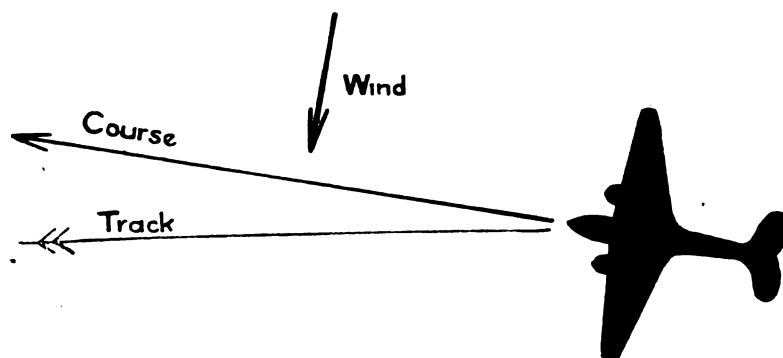


FIGURE 2. 10° Port Drift.

8. The practical importance of the measurement of drift as a means to an end cannot be over-emphasized. If the Navigator can predict what drift he is likely to experience on various Courses, he can choose a Course which, together with the drift, will give him a required Track.

9. Thus, a Navigator who wishes to fly from A to B, a Track of 090° T, may compute a drift of 10° to Starboard, on a Course of 080° T. Clearly, this will be the requisite Course, since, by allowing for the drift, the required Track is made good. It should be clearly understood that *the drift still exists*. The Course has simply been adjusted to fit the conditions of the flight.

10. As another instance of the importance of drift measurement, consider the Navigator who wishes to know what Track he is making good over the Earth. He will know the Course of the aircraft; by measuring the drift, and applying it to the Course, the Track is deduced.

11. Drift plays an important part in the various methods of determining Wind Velocity in flight described later in this Chapter. Indeed, its measurement should be constantly in the Navigator's mind, **who must lose no opportunities of checking drift.**

The numerous practical methods available to the Navigator for finding drift are detailed in Chapter XII, paragraph 32.

Primary Navigational Problems Based on the Triangle of Velocities

12. The six parts of the triangle of velocities are all variable, and hence there are no fewer than fifteen different combinations of two unknown factors, capable of solution from a knowledge of the other four factors. The Air Navigator is, however, usually concerned with only three general sets of problems, for the reason that some of the variables are usually determined by conditions beyond his control. For example, the Airspeed of the aircraft is usually determined by operational requirements and by the capabilities of the aircraft, and the Navigator will seldom be concerned with adjusting the Airspeed to suit purely navigational requirements. Similarly, a flight between two points defines the Track that the aircraft must follow. Hence the Track will on many occasions be known. Again, Wind Velocity cannot be adjusted to navigational requirements, although some selection is usually possible whenever a choice of height exists.

13. The three primary problems of Navigation must now be considered in detail. The plotting of navigational problems is simplified if it is remembered that *the Wind always blows the aircraft FROM its air position TO its ground position, and Wind Direction is always that FROM which the Wind blows.*

Finding the Track and Ground Speed of an Aircraft, Knowing Course, True Airspeed and Wind Velocity

Example :—

14. An aircraft on a Course of 090° T whose True Airspeed is 250 k, experiences a Wind of $025^\circ/25$ k. What is its Track and Ground Speed? (See Figure 3.)

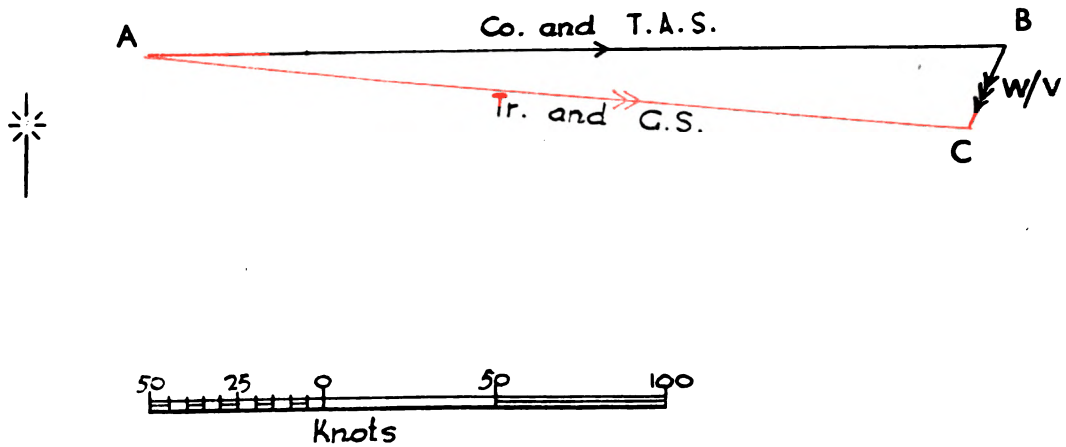


FIGURE 3. Finding Track and Ground Speed.

Draw a line AB in length and direction to represent the True Airspeed and Course of the aircraft. (B therefore represents the air position of the aircraft after flying one hour.)

From B draw BC to represent the Wind *down wind* for one hour. (C now represents the ground position of the aircraft after one hour.)

Join AC, which represents the Track and Ground Speed in direction and length to scale for one hour. The Track is found to be 095° T and the Ground Speed 240 k.

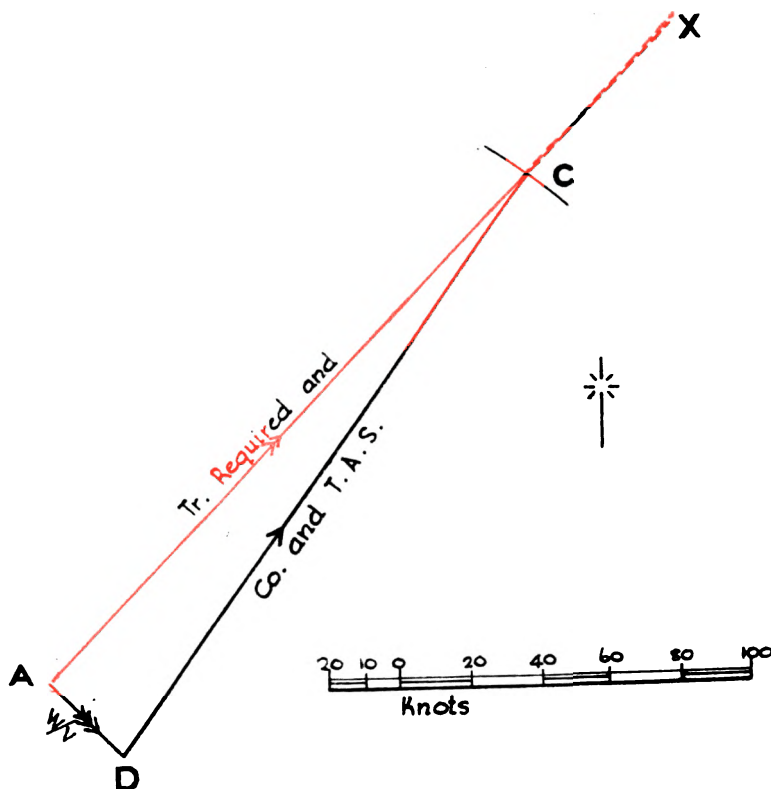


FIGURE 4. Finding Course and Ground Speed.

Finding the Course and Ground Speed of an Aircraft, given True Airspeed, Track Required and Wind Velocity

Example:—

15. An aircraft whose True Airspeed is 200 k, is required to make good a Track of 045° T. The W/V is $315^\circ/30$ k. What is its Course and Ground Speed? (See Figure 4.)

Draw a line AX in a direction of 045° T, to represent the Track required. From A draw AD to represent, to scale, the Wind, down-wind for one hour.

Suitable allowance has now been made for the effect of the Wind, for one hour.

With D as centre, and radius the True Airspeed to scale, cut AB at C.

DC then represents the Course in direction, which is found to be 037° T.

AC represents, in length, the Ground Speed to scale, 197 k.

16. It will be remarked that the triangle of velocities used in this case is the opposite of that used in paragraph 14, being the other half of the parallelogram of velocities. (See Chapter II, paragraph 30.)

Finding Wind Velocity

17. There are more than a dozen ways of finding the Wind Velocity in flight. While all are based on the fundamental triangle of velocities, some have more general application than others, and some require special equipment. The practical Air Navigator uses those methods most convenient under the varying circumstances of flight, paying due regard to the over-riding requirement of accuracy of results. In the paragraphs that follow, a review is made of the various methods. The importance to be attached to each method is also indicated.

Track and Ground Speed Method

18. This is the most valuable method of wind-finding owing to its simplicity, and because plotting is not required if a Navigational Computer Mk. III is used. If the Track and Ground Speed are measured accurately in flight, the primary triangle of velocities can usually be solved, since the Navigator should know the Course and True Airspeed.

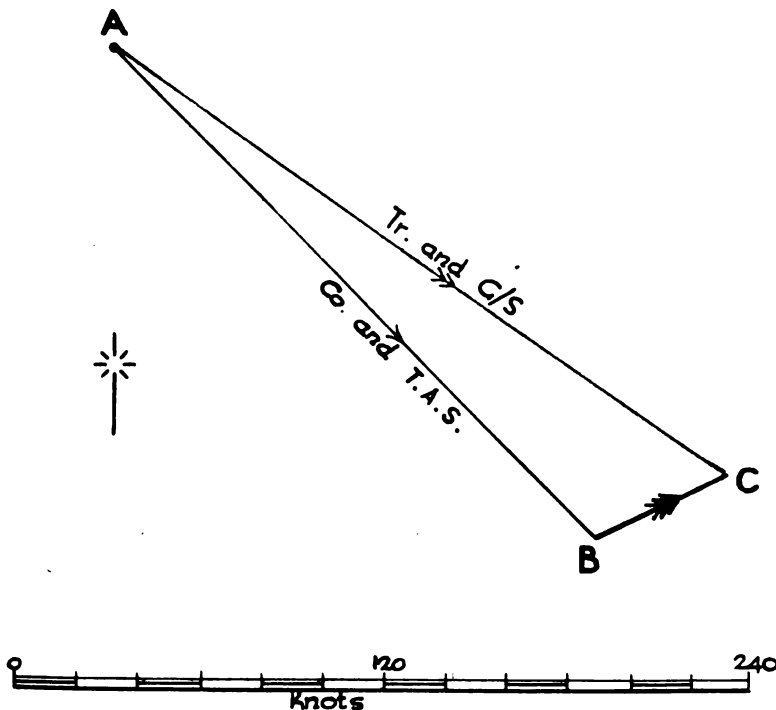


FIGURE 5. Wind-finding: Track and Ground Speed Method.

Track and Ground Speed can be measured most accurately from two reliable fixes obtained while flying a straight Course and steady Airspeed. Thus two visual pin-points afford excellent data. The reliability of fixes and their consequent utility for wind-finding purposes are both discussed in Chapter VI, paragraphs 18, 19, 20.

Track and Ground Speed can also be measured by observing the passage of some prominent mark on the ground or sea, through an instrument such as the Drift Recorder Mk. II, or the Course-Setting Bomb-Sight. All such observations are likely to be unreliable for finding Ground Speeds as it is usually impossible to tell exactly the height of the aircraft above the object selected. Moreover, despite the skill of the average Pilot, the Course and Airspeed vary continuously, and one short interval of time will not always represent the general progress of the aircraft with sufficient accuracy for wind-finding.

Example:—

19. The Navigator of an aircraft flying at a True Airspeed of 220 k on a Course of 135° T, observes a fix at 09.00 hours. A second fix is observed at 09.12 hours. The distance and direction of the second fix from the first are 48 n.m., 124° T respectively.

The Ground Speed is calculated to be $48 \times 5 = 240$ k. The Track is evidently 124° T. The Wind Velocity may be found by plotting the velocity triangle.

In Figure 5, AB is the Course and True Airspeed vector.

AC is then drawn to represent the Track and Ground Speed to scale.

$\therefore$ BC is the Wind vector, and represents a velocity of $244^\circ/48$ kg.

Air Pilot Method

20. This is a very valuable method of wind-finding, capable of almost universal employment and of giving excellent practical results provided the plotting and timing are accurate, and provided a reliable fix is used. It is based on a comparison between the air position of the aircraft and its ground position whenever the latter becomes known. The distance and direction of the ground position from the air position is clearly the effect of the Wind since the Air Plot was begun. The Wind Speed is then found by simple proportion.

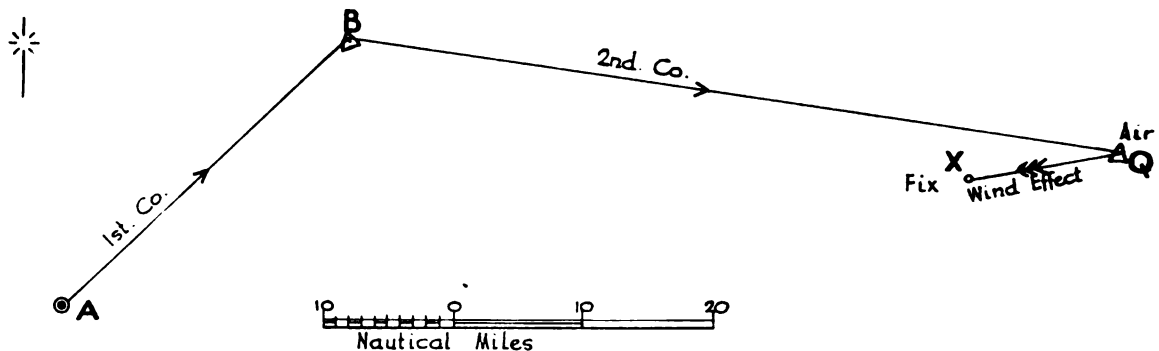


FIGURE 6. Wind-finding: Air Plot Method.

Example:—

21. Ten minutes after leaving an aerodrome A on a Course of 047° T, the Navigator of an aircraft cruising at a True Airspeed of 180 k altered Course to 098° T. After a further 20 minutes, the aircraft passed over X on which the Navigator fixed his position.

To find the Wind, the Navigator plots the Courses steered and the air distances flown on each, namely AB, BQ in Figure 6.

Q was the air position when X was the aircraft's ground position. The Wind had therefore carried the aircraft from Q to X in $(10 + 20 =) 30$ minutes.

The direction from which the Wind had evidently blown was 080° T, and QX measures 12 n.m.

In one hour, the Wind would have carried the aircraft $\frac{12 \times 60}{30}$ n.m. = 24 n.m.

The Wind Velocity was therefore $080^\circ/24$ k.

22. It should be fully understood that the number of alterations of Course have no effect on the Wind found, so long as the Air Plot is kept accurately. If, however, the Air Plot is maintained for a considerable time, the aircraft may experience a gradual change in Wind Velocity and the Wind found by Air Plot will only be a *Mean Wind Velocity*, which may be far from representative of the Wind experienced at any particular instant or at any one stage of the flight. A Mean Wind Velocity may be of great practical use in the area as a whole in which it was found. It is often quite useless for calculating Courses for Tracks through other areas, and should therefore be employed with reserve.

Multiple Drift Method

23. This consists of observing drift on two or more Courses when the True Airspeed is known. It is one of the most reliable methods available, since its accuracy can be quickly checked. It is extremely simple and can be used universally, at any time when drifts are obtainable.

If two or more aircraft are assumed to arrive at a common air position after a given time-interval and their Tracks are measured by drift readings, then in any given Wind they must all have a common ground position, namely where their Tracks intersect. The Wind effect in the assumed period of time can be found by measuring the direction and distance from the air position to the ground position. The Wind may be found by plotting or by using the Navigational Computer Mk. III. (See Chapter XII, paragraph 83 (iv).)

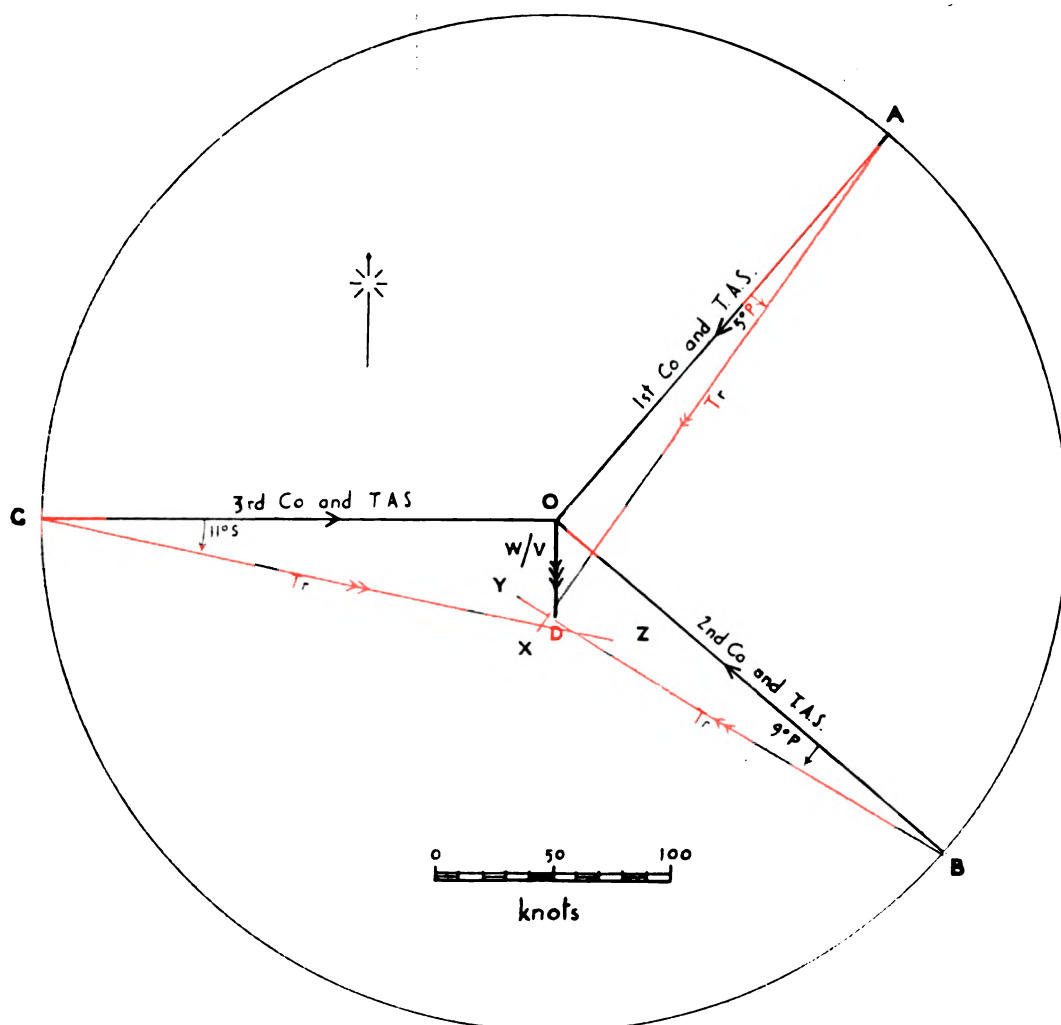


FIGURE 7. Wind-finding: Multiple Drift Method (i).

To ensure a satisfactory cut between the Tracks, it is advisable to measure drifts on substantially different Courses. A difference of less than 30° between Courses may give rise to inaccuracy and ambiguity.

Example:—

24. An aircraft flying at 220 k is on a Course of 220° T and the Navigator observes 5° Port drift. The Course is now changed to 310° T and the drift is measured and found to be 9° Port. A third Course of 090° T is flown as a check and drift is found to be 11° Starboard.

(i) Draw a circle of radius 220 k to scale. (This is called an Airspeed Circle.) From the centre O, draw OA, OB, OC as radii in the *reverse* direction of the three Courses flown, namely 040° T, 130° T and 270° T. AO, BO, CO represent the three Courses of one hour's duration from points on the circumference, all meeting at a common air position, O, after one hour, as signified by arrows in Figure 7.

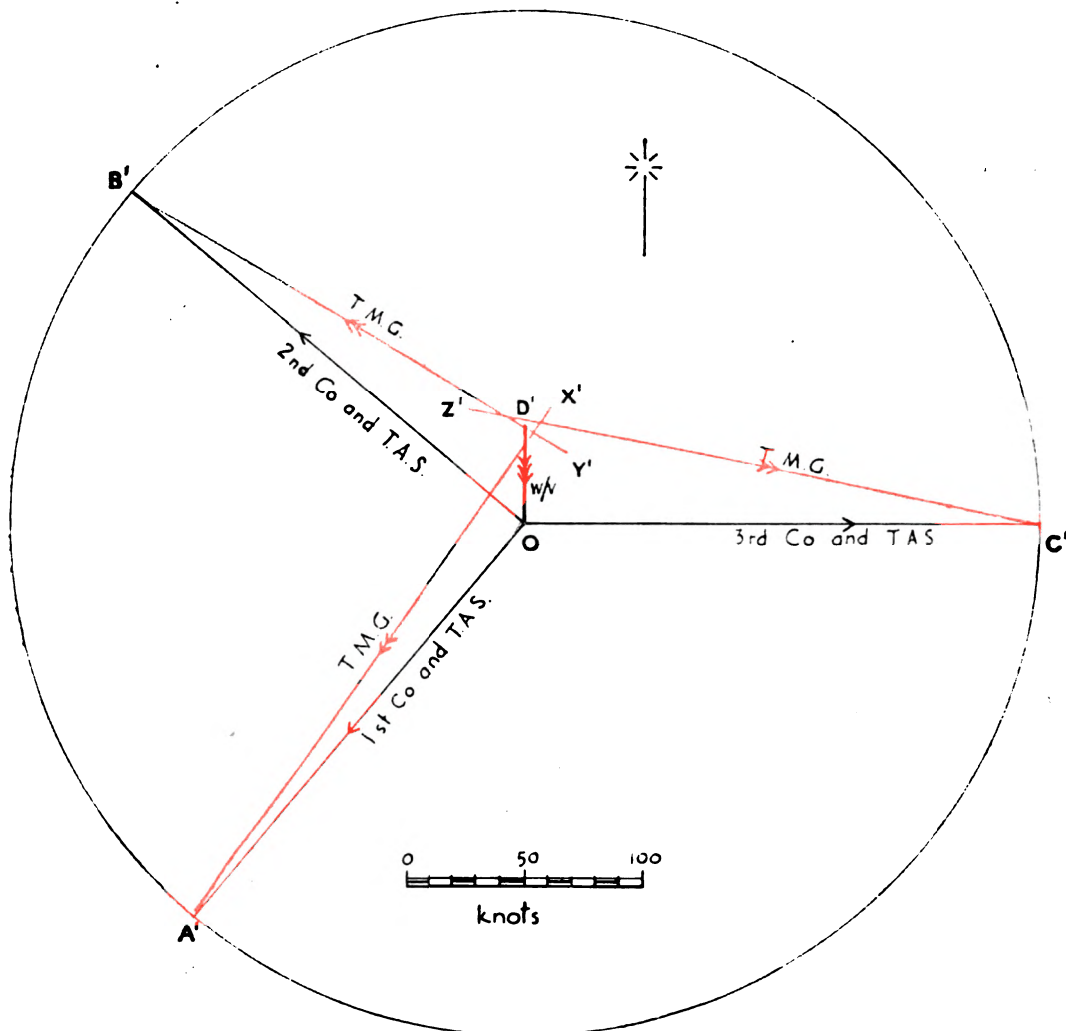


FIGURE 8. Wind-finding: Multiple Drift Method (ii).

By applying the drifts concerned, lay off AX, BY, CZ to represent the Tracks made good. AX, BY and CZ should meet at one point since the Wind would affect all Courses equally in the same interval of time (one hour). Since by construction there is a common air position, O, to all three Courses *after* one hour, there must also be a common ground position. This is at D, the intersection of the three Tracks. In practice the observations of drift will not be absolutely accurate, and the intersection of

the three Tracks, AX, BY and CZ will usually take the form of a "cocked hat," the centre of which is chosen as the "wind point", D. (See Figure 7.) The same remarks apply to the "cocked hat" as are made in Chapter VI, Paras. 14-16. Generally speaking the size of the "cocked hat" is indicative of the accuracy of the observation, and data giving large "cocked hats" should be disregarded.

The Wind for one hour is obtained by measuring OD, which is found to represent 42 k, from 000° T. The W/V is therefore $000^\circ/42$ k.

(ii) The Wind may be plotted by drawing from the centre O the *actual* Courses *outwards* to the circumference; and from the points on the circumference, the Tracks on each Course are then plotted *backwards*, to intersect at the wind point D¹ (See Figure 8). In this construction the Wind blows to the centre O from D¹. To avoid confusion always use Method (i) and mark the vectors with arrows.

Drift and Wind Lane Method

25. This method is valuable for Navigation over water at heights not in excess of 1,500 feet. Since the data must contain a drift reading, the method is impracticable when the Course of the aircraft is either up- or down-wind, or nearly so.

Drift is measured and the Track of the aircraft is thereby determined. By observing with a compass, or other means, the direction of the "wind lanes" on the surface of the sea, the direction of the *surface* Wind is also determined.

As a general rule, over the sea the Wind direction at 1,500 feet is about 10° *more* than at the surface. This tendency to "veer" can be applied *pro rata* for intermediate heights, but is too uncertain for extension above 1,500 feet. In some cases the direction may "back" or decrease with an increase of height, and hence care must be taken in applying the method.

Since the Course and True Airspeed are already known, four of the six variables in the triangle of velocities are known, and the remaining two, Wind Speed and Ground Speed may be plotted or calculated.

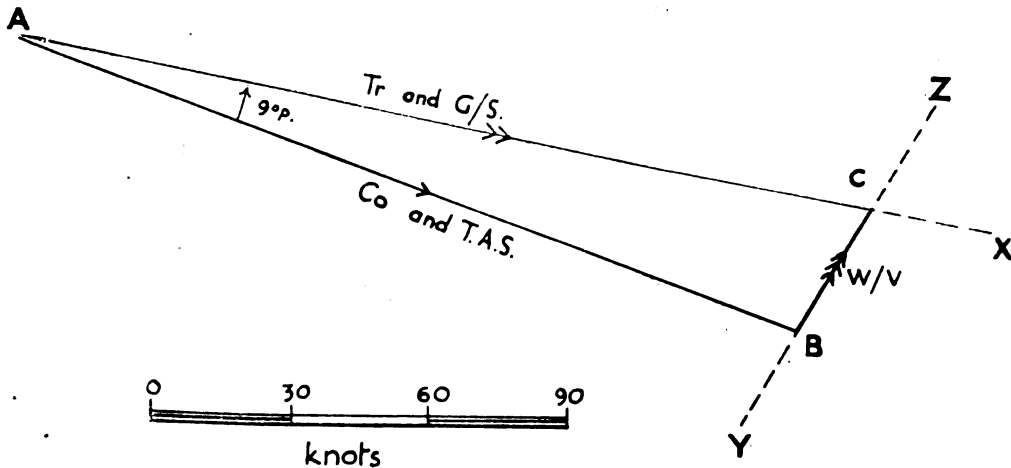


FIGURE 9. Wind-finding : Drift and Wind Lane Method.

Example:—

26. An aircraft flies at 1,500 feet, CO. 110° T.A.S. 180 k. The wind lanes bear 201° T and 021° T, and the drift is 9° to Port.

Judging by the drift it is clear that the Wind Direction at the surface is *from* 201° T. Applying the rule laid down above, it is clear that at 1,500 feet the Wind Direction is probably $(201^\circ \text{ T} + 10^\circ =) 211^\circ$ T.

Draw AB to represent the Course and True Airspeed in direction and length.

Draw AX to represent the Track in direction, 101° T.

Through B, draw YZ in the direction the Wind is blowing at 1,500 feet, from 211° T to 031° T cutting AX at C.

Then BC represents in length the Wind Speed to scale, i.e., 30 k.

The W/V is therefore $211^\circ/30$ k.

(Note.—AC represents in length the Ground Speed to scale, i.e., 188 k.)

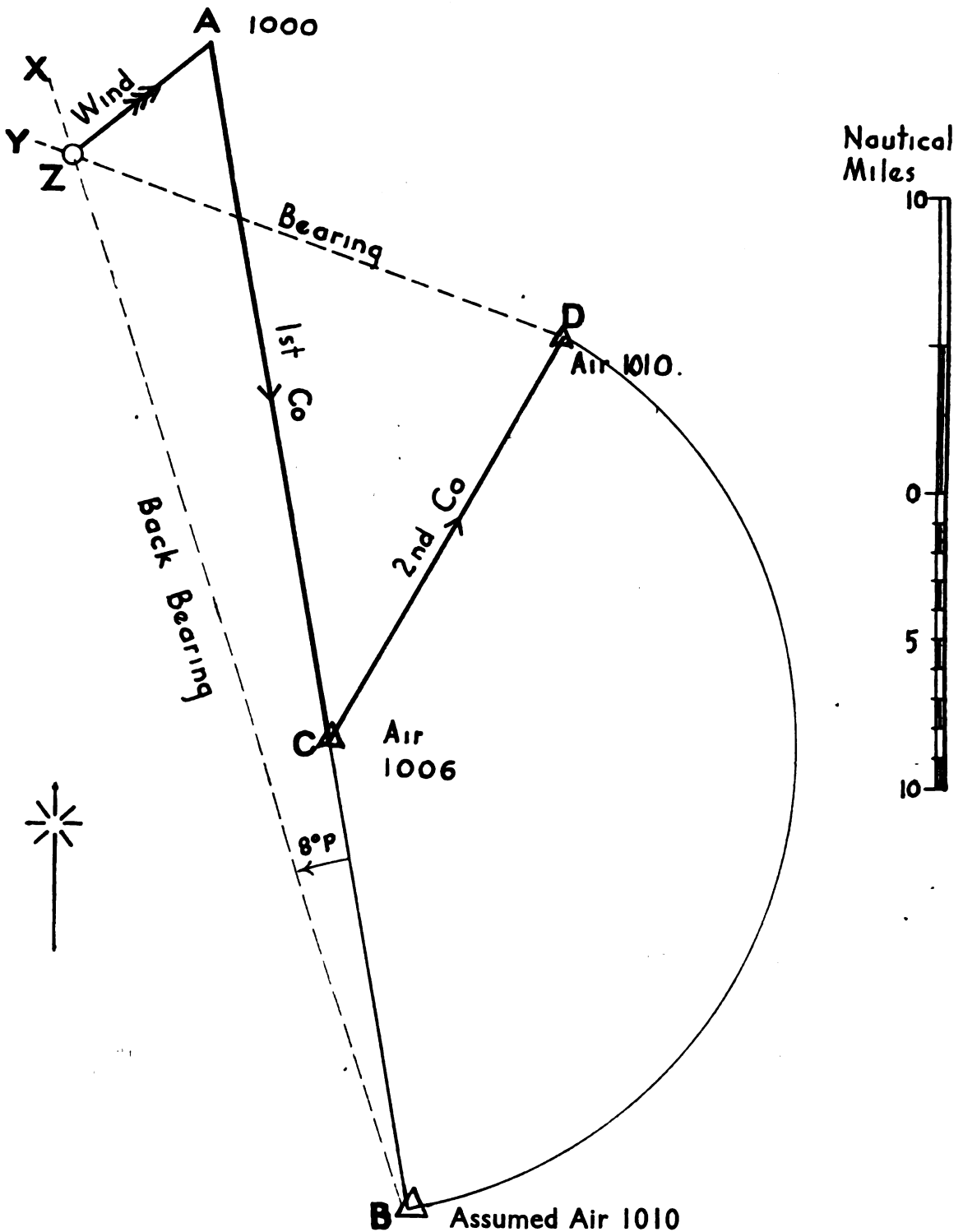


FIGURE 10. Wind-finding : Drift and Bearing Method.

Drift and Bearing Method

27. This method is capable of wide application and is useful when making a turn at, or shortly after flying over a prominent land- or sea-mark.

The Navigator takes the time of departure from the selected mark and observes the True back-bearing either directly by bearing compass or by applying drift to the True Course and taking the reverse of the Track. This back-bearing will remain unchanged as long as the aircraft maintains its Course and True Airspeed.

At a convenient time a new Course is set, so that the selected object will remain in view, or else return to view if it has already disappeared.

After a further interval of time, and while the object is still visible, a bearing is taken of the object, the time again being noted. If the selected object provides D/F facilities, the bearings described can be found when the object is beyond visible range.

The Wind Velocity is found by plotting. (See Figure 10.)

Example:—

28. An aircraft flies at 240 k and passes over point A at 10.00 hours on a Course of 170° T. The drift is 8° to Port. At 10.06 hours Course is altered to 030° T, and at 10.10 hours the bearing of A is 290° T.

Draw AB to represent the air distance flown between 10.00 hours and 10.10 hours, i.e., 40 n.m. (to scale), supposing that no alteration of Course was made at 10.06 hours.

Mark off AC to represent the distance flown from 10.00 hours to 10.06 hours on the first Course, i.e., 24 n.m. (to scale).

From C draw CD in a direction of 030° T, equal in length to CB. Then CD represents the air distance flown on the second Course from 10.06 hours to 10.10 hours.

From B draw a line BX to represent the original back-bearing of A, or reversed Track, that is $(170^\circ - 8^\circ \pm 180^\circ =) 342^\circ$ T.

From D draw DY representing the second bearing of A, namely 290° T. DY cuts BX at Z, and since both bearings are in effect simultaneous bearings of the same object A, their intersection constitutes a fix.

Z is the *apparent* position of A after the Navigator has been flying for 10 minutes.

ZA is therefore the Wind effect for 10 minutes. It represents 6 n.m. from a direction of 230° T.

The Wind Velocity is therefore $230^\circ/36$ k.

Drift and Position Line* Method

29. This is a recent development of the Drift and Bearing Method that has something to commend it. It necessitates plotting. The aircraft takes departure from a recognisable pin-point, and flies a succession of Courses of known duration. After some time a position line is obtained. This must be as accurate as possible, e.g., preferably a transit.

Either before or after obtaining the position line, a drift is observed on a Course nearly at right-angles to the position line. The Wind Velocity is then obtained by plotting.

Example:—

30. An aircraft leaves a pin-point P at 09.00 hours, cruising at a True Airspeed of 220 k on a Course of 085° T.

At 09.06 a Course of 125° T is set.

At 09.08 a Course of 070° T is set.

At 09.11 a Course of 140° T is set.

At 09.15 an accurate bearing of a Lt. V., 0, is found to be 189° T.

At 09.18 a Course of 099° T. is set.

Drift is observed to be 7° starboard.

As in Figure 11, plot the air position B, of the aircraft at 09.15 hours.

From B lay off BA, the reverse of the Course on which the drift was obtained, that is $(099^\circ \text{ T} \pm 180^\circ =) 279^\circ$ T. AB equals the air distance flown since departure from point P until the moment the position line was obtained. That is, 15 minutes at 220 k, a distance of 55 n.m.

From A lay off AX, the imaginary Track made good on this Course (i.e., apply the drift). AX cuts the position line at C.

* See Chapter VI for explanation of position lines.

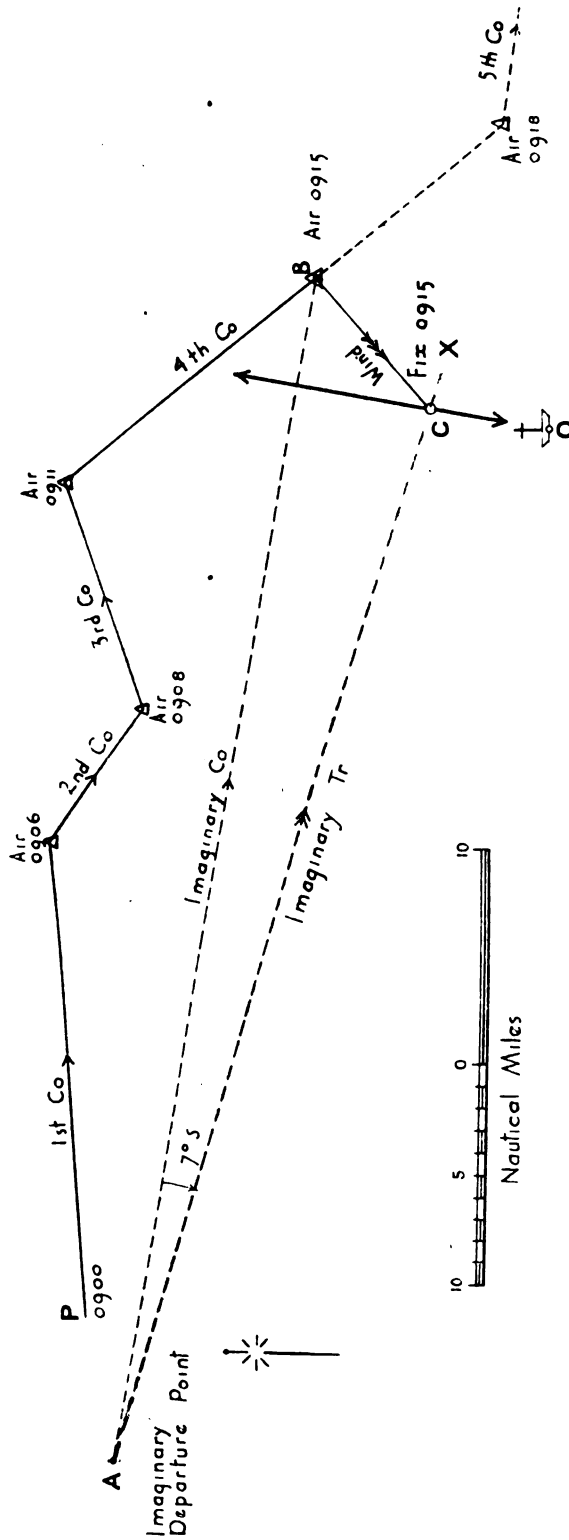


FIGURE 11. Wind-finding : Drift and Position Line Method.

Then BC is the Wind effect for the time between leaving the fix at P, and obtaining the position line, 15 minutes later in this case. BC is found to measure 8 n.m. from a direction of 048° T.

The Wind Velocity is therefore $048^\circ/32$ k.

*Note :—*By finding drift on a Course that is nearly perpendicular to the position line, a clean intersection at C is ensured.

31. If a long time elapses between leaving the fix and obtaining the position line, the Wind found will only be a compromise between the *mean Wind* (which is responsible for the position line obtained) and the instantaneous Wind (which gives the drift by which the fix is obtained). In this event it may be necessary to adopt an arbitrary scale of distance in order to accommodate the length of the imaginary Course upon the map. A scale plot can be drawn at any convenient position, the position line being re-positioned at the chosen scale with reference to the air position.

Proof :—

32. AB is an imaginary Course for 15 minutes' flight up to the known air position B. AX is the corresponding imaginary Track.

At 09.15 hours the known position of the aircraft is situated somewhere on the position line. Obviously, the intersection of the imaginary Track with this position line gives a true fix, since the Wind effect in the given time (15 minutes) is the same whatever the Courses flown.

Reverse Track Method

33. This method has proved useful under certain limited conditions.

The Navigator notes the time of departure from a certain defined landmark, and Drift is measured.

After a convenient time-interval, the aircraft is turned on to a Course giving the reverse Track (see Chapter X, paragraph 2). The time-interval is again noted on the return journey to the original landmark.

The Wind Velocity is found by plotting.

34. It should be noted that the method is useful if, towards the outward end of a patrol, the Navigator observes a suitable object over which he passes. Modern aircraft have a fairly large turning radius and therefore the aircraft would not normally return directly over the object. This may be eradicated by neglecting the actual time spent in the turn, and asking the Pilot to set the second Course over any suitable mark (not necessarily a pin-point) at the end of the patrol, the timing being observed between the first object and this mark and back again.

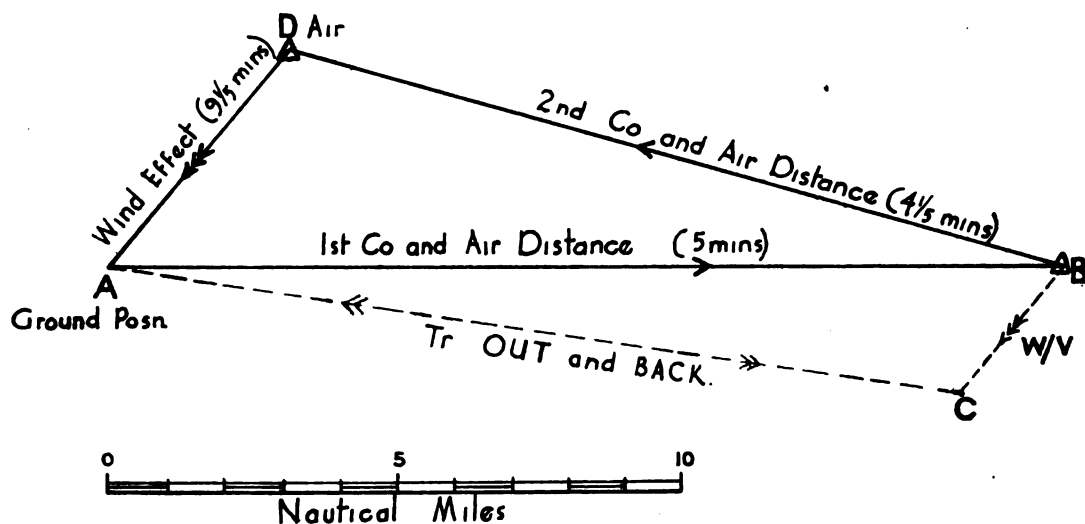


FIGURE 12. Wind-finding: Reverse Track Method.

Example :—

35. An aircraft flying on a Course of 090° T at 200 k, passes over an object A at 09.00 hours. The drift is 8° to Starboard. At 09.05 hours the aircraft arrives over a mark C. At 09.07 hours the aircraft is set on a Course from C of 286° T and arrives over A at 09.11.12 hours. (See Figure 12.)

Draw AB to represent in length and direction the air distance and Course on the outward journey to scale (5 minutes at 200 k =) 16.7 n.m.

Draw BD to represent in length and direction the air distance and Course on the return journey to scale (4.2 minutes at 200 k =) 14 n.m.

Then D is the air position of the aircraft at 09.11.12 hours, when its ground position is A. It follows that the Wind has blown from D to A, a distance of 5 n.m., in (5 + 4.2 =) 9.2 minutes.

The Wind Velocity is 040°/33 k.

It may be noted that the aircraft proceeded from A to C and back, after the turn, but for the purpose of wind-finding, the actual Track is of no concern to the Navigator.

Reverse Course Method

36. This method has few practical applications to Navigation in high-speed aircraft. It does not necessitate plotting and for this reason is commendable to Pilot-Navigators.

The aircraft is directed over an easily recognised land- or sea-mark, the time is noted, and a Course set.

After a suitable time interval the aircraft is turned on to the reverse of the first Course, the manoeuvre being carried out as described in the preceding method; that is, by neglecting the time taken in the turn, and setting a Course from a mark (not necessarily a pin-point) observed at the end of the outward run.

After flying the *same time* on the second Course as on the first, the aircraft is turned towards the original land- or sea-mark, the time again being noted. If the first Course was steered approximately *down-wind*, the final turn towards the original object will be only a slight one.

The aircraft will now be flying directly up-wind, and the True Course indicates the Wind Direction.

The time is again noted when the aircraft passes over the original object, and the Wind Speed is calculated from the formula :

$$W = \frac{At}{T + t}$$

where W = Wind Speed
 A = True Airspeed
 t = Time on the third Course
 T = total Time (in comparable units) of the first two Courses, less time to turn.

Example :—

37. An aircraft flies on a Course of 270° T from a landmark, A, at 200 k. After 3 minutes, a turn is made through 180°, a Course of 090° T being set.

After a further 3 minutes on the second Course, the Pilot flies directly towards A, which he reaches after a further 40 secs., on a Course of 060° T. (T = 6 minutes or 360 seconds.)

The Wind Speed is therefore $\frac{200 \times 40}{360 + 40} \text{ k} = \frac{200 \times 40}{400} \text{ k} = 20 \text{ k}.$

The Wind Velocity is 060°/20 k.

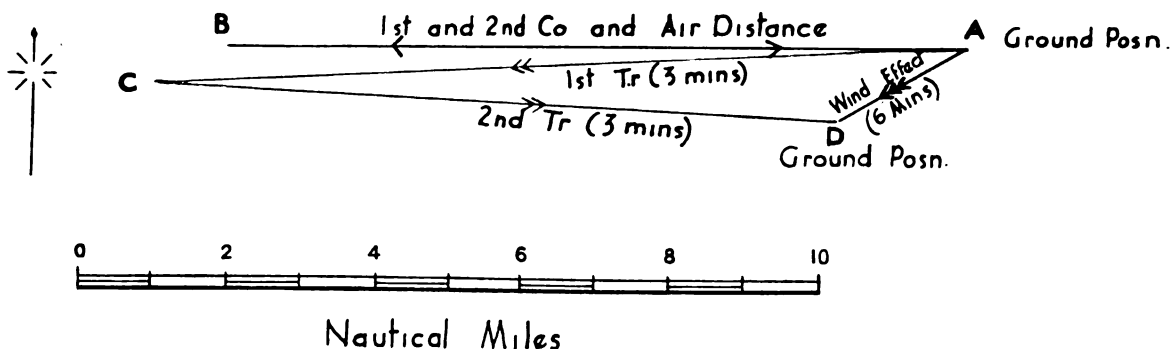


FIGURE 13. Wind-finding : Reverse Course Method.

Derivation of the Formula

38. Figure 13 illustrates the case in point. AB and BA represent the two Reverse Courses flown for 3 minutes each way.

AC and CD represent the first two Tracks flown by the aircraft.

Thus when after 6 minutes' flight ($T = 360$ seconds), the aircraft's air position is at A, its ground position is D.

The aircraft proceeds from D to A in 40 seconds (t) at a Ground Speed equal to 200 k minus the Wind Speed, $(A - W)$.

The distance AD can be expressed in two ways :

AD = the effect of the Wind in 6 minutes.

= Wind Speed $\times$ Time.

= $W \times T$

Also, AD = the distance travelled on the last Course in 40 secs.

= Ground Speed $\times$ Time

= $(A - W) \times t$

Equating the two expressions (1) and (2) :

$WT = (A - W) t$, W being unknown.

$\therefore WT = At - Wt$;

or, $Wt + Wt = At$,

$\therefore W(T + t) = At$.

Whence $W = \frac{At}{T + t}$

Smoke Cloud Method

39. This is a variation of the Reverse Course method, and also requires no plotting. Owing to its requiring a substantial and clearly visible smoke cloud, which does not rapidly disintegrate, the method is not always successful, and cannot be used at night.

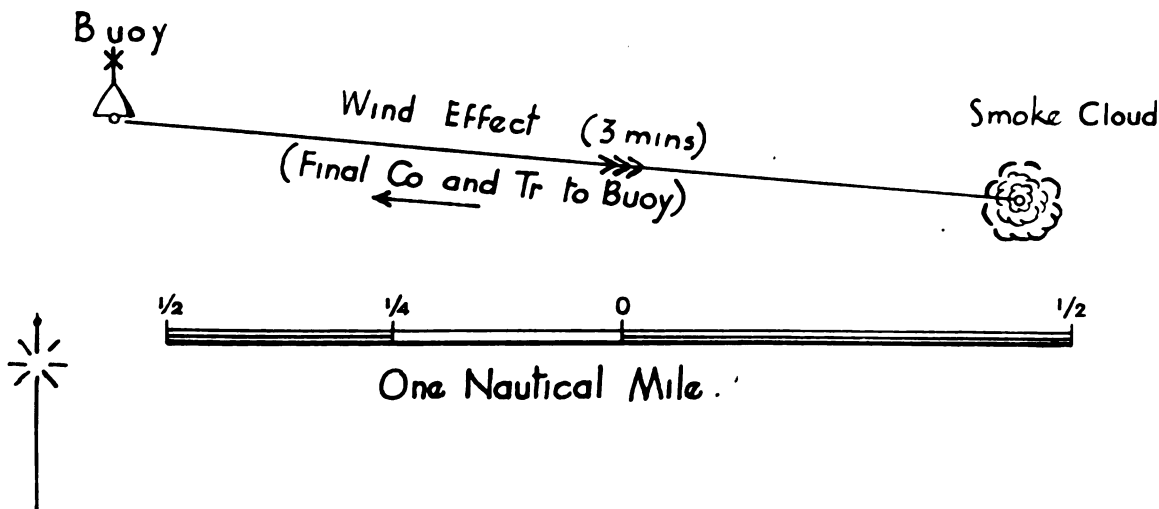


FIGURE 14. Wind-finding : Smoke Cloud Method.

The Navigator releases the smoke cloud when directly over a prominent land- or sea-mark, and a stop-watch is started. The Pilot is then directed to fly about in the vicinity, keeping the smoke cloud in view.

The cloud will be blown down-wind and be gradually dispersed. Before it finally disappears the Pilot must fly through the cloud towards the selected object. The time (T) of passing through the cloud is observed.

Since the aircraft will now be flying directly into Wind, the True Course indicates the Wind Direction.

Finally, the Time (t) of arrival over the selected object is observed.

The Wind Speed is then obtained from the formula :

$$W = \frac{A t}{(T + t)}$$

where W = Wind Speed,
A = True Airspeed

The derivation of this formula is identical with that for the Reverse Course method. The accuracy of results depends on firing the smoke cloud directly over the mark and on precise timing.

Example:—

40. An aircraft is flying at a True Airspeed of 125 k. The Navigator releases a smoke cloud over a buoy, and 3 minutes later directs the aircraft through it and towards the buoy, which is reached after a further 34 seconds on a Course of 285° C.

Deviation is 2° E and Variation 12° W.

The Course is therefore $(285^{\circ} + 2^{\circ} - 12^{\circ} =) 275^{\circ}$ T.

From the formula,

$$W = \frac{125 \times 34}{214} \text{ k} = 20 \text{ k approx. (using a circular slide rule).}$$

The Wind Velocity is therefore $275^{\circ}/20$ k. (See Figure 14.)

The 45° Bearing Method

41. This method is used over the sea but suffers from the disadvantages of being very complicated, of being unworkable when the Wind direction is ahead or astern of the aircraft, and of requiring special tables.

When the aircraft is over a prominent mark the Navigator releases a smoke cloud and starts a stop-watch. The Pilot then commences a 180° turn, and after flying on the reverse of the first Course for a convenient time, executes another 180° turn in the same direction as before, which brings him on to the original Course. If the two turns have been made at the same rate, the smoke cloud will be directly ahead, since both aircraft and smoke cloud have been affected equally by the Wind.

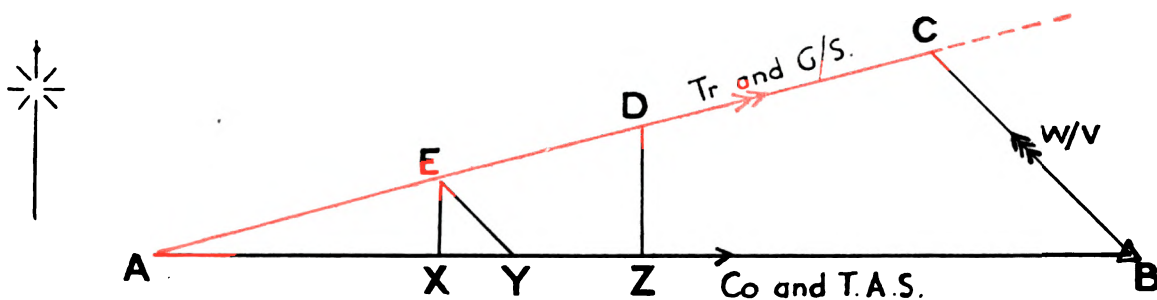


FIGURE 15. Wind-finding : 45° Bearing Method.

However, the smoke cloud will have been blown down-wind from above the mark. Thus when the aircraft approaches the smoke cloud, the mark will be observed to one side or other of the aircraft.

The Navigator notes the following times in seconds after passing the mark :

T₁ : When the aircraft passes through the smoke cloud again.

T₂: When the bearing of the mark is 90° from the aircraft's head.

T₃: When the mark bears 135° from the aircraft's head.

Note.— T_0 will be less than T_1 if the Wind Direction is more than 90° from the aircraft's head.

42. In addition to taking these times, the Navigator should take a bearing of the mark at the moment of passing through the smoke cloud, since this gives a check on the Wind Direction.

If the subsequent calculations give a Wind Direction differing considerably from the direction observed on passing through the smoke cloud, the data should be rejected, and another set of observations obtained.

The Wind is found by plotting, as follows : (See Figure 15.)

43. Draw a line AB representing in length the True Airspeed, and in direction the last Course steered.

Choosing any convenient scale (say 20 seconds = 1 inch), mark off AX, AY, and AZ to represent T_1 , T_2 and T_3 respectively.

From Z draw ZD, equal to ZY and perpendicular to AB, on the opposite side to that on which the mark was observed from the aircraft. Join AD.

At X draw a line perpendicular to AB and cutting AD at E. Join YE.

Through B draw a line parallel to YE, cutting AD (produced) at C.

Then BC represents the Wind for one hour.

Proof:—

44. The first manœuvre of the aircraft, from releasing the smoke cloud up to the time of passing through it again, is simply designed to obtain a smoke cloud that has been blown down-wind from a fixed datum point, Y, in a known time (T_1). Hypothetically when the smoke cloud is released over the mark, Y, the position of the aircraft may be considered as being at A in Figure 16, if AY is equal to the air distance flown from the moment of release to the moment of passing through the smoke cloud ; that is, air distance YRSY = air distance AY.

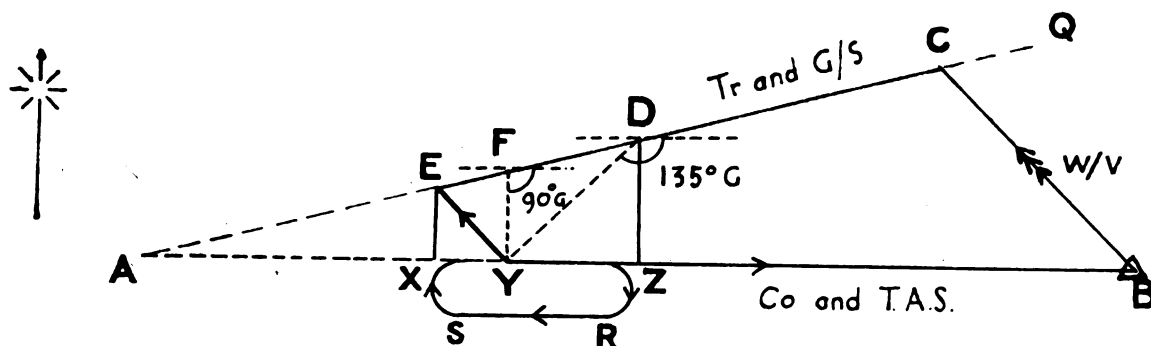


FIGURE 16. Proof of 45° Bearing Method.

By the time the aircraft has flown air distance AY, it will have been affected by the Wind for a time, T_1 , and so will be down-wind from the mark Y (which has, of course, remained stationary) a distance and direction represented by, say, YE.

Then AE, produced to Q, represents the Track of the aircraft ; while AY, produced to B, represents the Course of the aircraft.

When the mark, Y, bears 90° to Port or Starboard (in the case illustrated, to Starboard) the ground position of the aircraft will be at F, where the perpendicular at Y cuts AQ.

Similarly, when the bearing is 135° to Port or Starboard (in the case illustrated, to Starboard) the ground position of the aircraft will be at D, so that angle DYB is 45° .

Now, the distance along a Track travelled by an aircraft is directly proportional to the time. Consequently AE, AF and AD are proportional to T_1 , T_2 and T_3 respectively.

If EX and DZ are drawn perpendicular to AB, the divisions AX, AY and AZ are made proportional to AE, AF and AD respectively.

Therefore AX, AY and AZ are respectively proportional to T_1 , T_2 and T_3 . It should be noted that triangle YZD is right-angled at Z, and isosceles. Hence YZ equals DZ.

Finally, if AB represents the Course and True Airspeed of the aircraft for an hour, and AQ represents its Track, while YE is known to be the Wind Direction, it follows that BC, drawn parallel to YE, represents the Wind Direction and Speed for one hour. (AC is then the Ground Speed.)

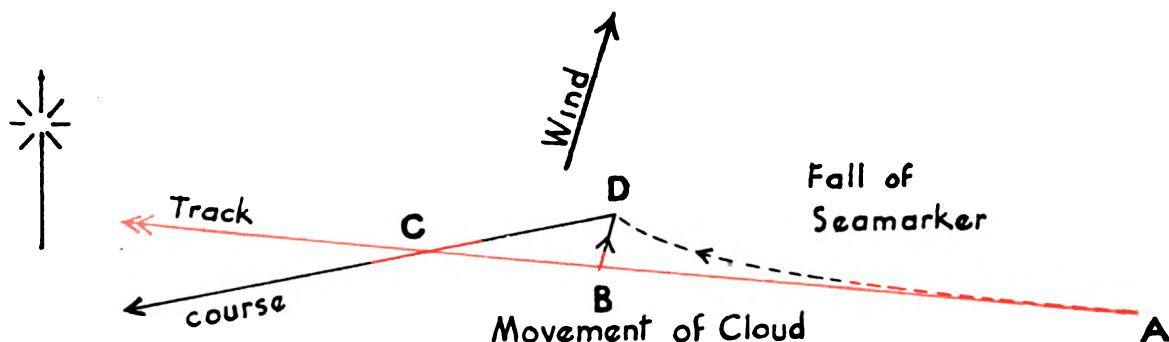


FIGURE 17. Timing the Sea-marker and Cloud.

45. In order to be of use over the sea, it is necessary to drop a sea-marker some time prior to releasing the smoke cloud, the time-interval being regulated by the ballistics of the sea-marker, the height and, to some extent, by the speed of the aircraft, so that both sea-marker and smoke cloud are in the same position at a known moment of time.

Since the sea-marker will enter the sea at a point in line with the *Course* of the aircraft, but at a distance behind it, it is necessary to release the cloud at such a time *before* the marker enters the sea that the cloud will have been blown, in the interval, down-wind to the position of the sea-marker.

In Figure 17, an aircraft flying on a Course of 260° T makes good a Track of 275° T. At A, the sea-marker is dropped, and this enters the sea at D, when the aircraft is at C. The smoke cloud has to be released at a time when the aircraft is at B, so that while the sea-marker continues to fall, the cloud will have drifted down-wind to position D.

46. These times have been calculated and the following Table is prepared for use with Smoke Floats Mks. III and IV :—

Height above Sea	Time (i) between Releasing Smoke Float and Firing Artificial Cloud				Time (ii) Fall of Smoke Float, (Mks. III and IV)			
Feet	Airspeed (knots)				Airspeed (knots)			
	90	115	130	150	90	115	130	150
	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.
2,000	9	9	8	8	13	13	13	13
4,000	11	11	11	10	20	20	20	20
6,000	13	12	12	11	26	26	27	27
8,000	14	14	13	12	32	33	33	33
10,000	15	14	14	13	38	38	38	38

The times in the above table should be used as follows :—

- Drop the Smoke Float, start the stop-watch.
- When interval (i) has elapsed, release the Artificial Cloud.
- When interval (ii) has elapsed after (a), stop and restart stop-watch and proceed to turn for Wind-finding.

The 90° Method

47. If this method is to be successful, the approximate direction of the Wind must be known by the Navigator. Obviously this seriously limits its usefulness.

The aircraft is directed as nearly as possible up- or down-wind by means of drift observations.

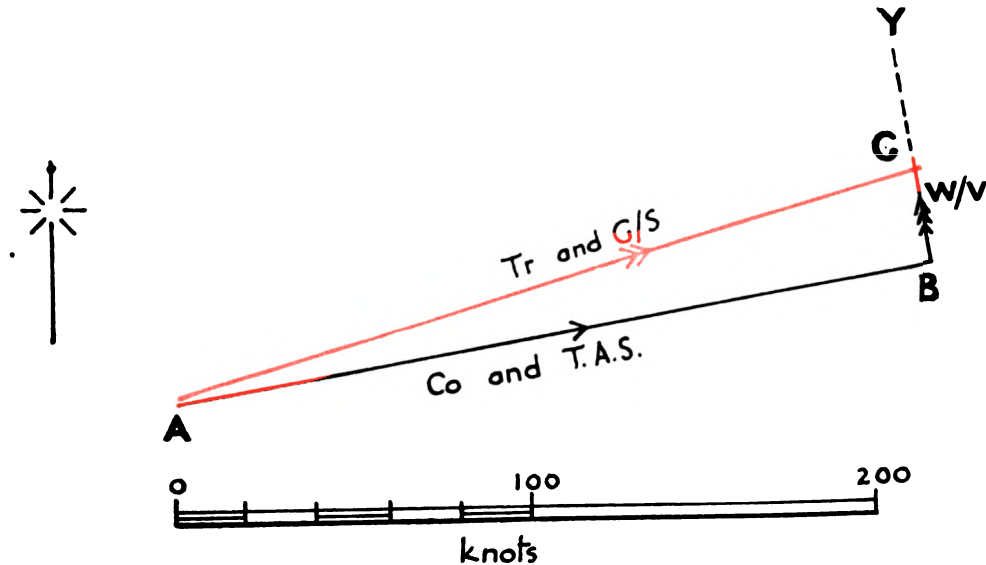


FIGURE 18. Wind-finding: 90° method.

When zero drift is observed, it is presumed the aircraft is heading up- or down-wind, and the True Course noted.

Course is then altered 90° to Port or Starboard, and drift is read. This will at once indicate whether the first Course was flown up- or down-wind.

The Wind Speed is found by plotting.

Example:—

48. An aircraft, True Airspeed 220 k, has to be flown on a Course of 350° T, so that no drift is discernable. A Course of 080° T is then set, and 8° Port drift is observed. (See Figure 18.)

Draw AB to represent in length and direction the True Airspeed and *second* Course to scale.

Draw XA, making angle XAB equal to the drift observed, i.e., 8° to port.

Draw YB perpendicular to AB, and cutting XA at C.

Then ABC is the triangle of velocities, in which BC is the Wind vector.

The Wind is found by measurement to be 170°/30 k.

Relative Wind Velocity

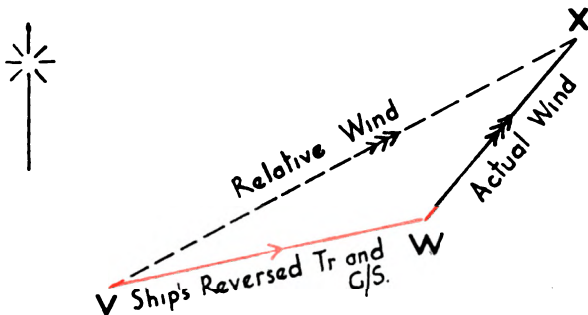


FIGURE 19. Wind-finding: The Relative Wind.

49. The Wind experienced by an observer on a moving ship is called the *relative Wind*. In conditions of dead calm such an observer would experience an apparent Wind of equal but opposite velocity to that of the ship. When there is a Wind blowing, the observer would experience a Wind resulting partly from the true Wind and partly from the apparent Wind due to the motion of the ship.

The true Wind may readily be found by means of the triangle of velocities if it is remembered that the *relative Wind is the resultant* of the true Wind and of the ship's Track and Ground Speed reversed. For example, from any point V (see

Figure 19) lay off the relative Wind, VX, down-wind. From V lay off VW, the ship's Track and Ground Speed reversed. Then WX is the true Wind Velocity. Note that the true Wind arrow and the ship's reversed Track arrow follow each other round the triangle.

50. When the Wind Velocity is found in the air by means of observations of a moving ship, the methods are carried out in exactly the same way as with a fixed object. It is only necessary to remember that the true Wind always blows from the Air position to the *actual* Ground position.

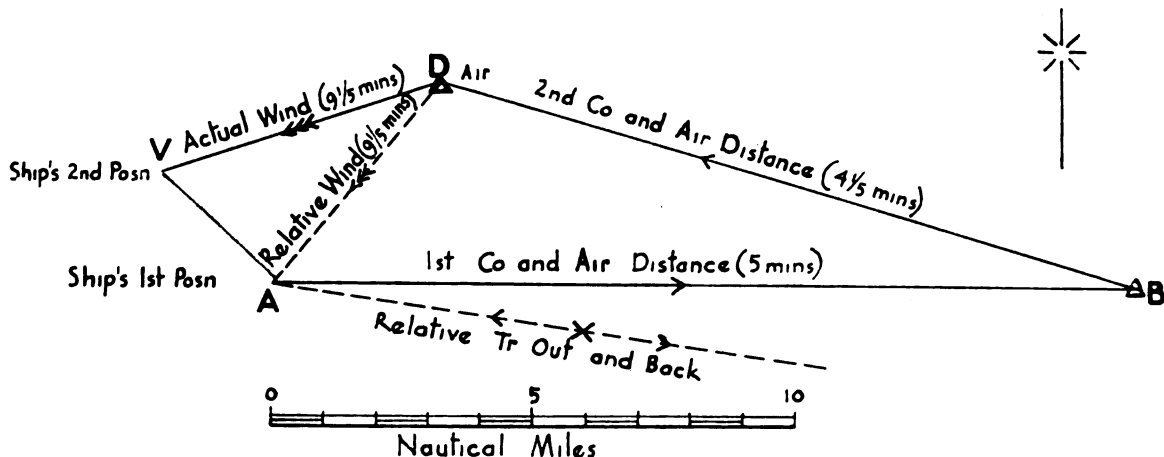


FIGURE 20. Wind-finding: Reverse Track Method Applied to a Moving Datum.

Figure 20 shows the same example of finding Wind by Reverse Track method as was illustrated in Figure 12, with a ship as datum whose velocity is 315° T, 20 k. On the outward journey a steady bearing of 098° T from the ship is maintained by steering, say, 090° T. It should be noted that the "Track" of 098° T, laid off on the plot, is the Track *relative to the ship*, and must not be confused with the actual Track over the sea. The inward Course is calculated to be 286° T, as before; and the aircraft arrives back over the ship 9.2 minutes after leaving it, assuming no time is lost on the turn, as was the case in the example given in paragraph 35. DA therefore represents the relative Wind for 9.2 minutes. The true Wind is found by laying off AV to represent the ship's movement in 9.2 minutes (i.e., 315° T, 3.1 n.m.). D is then the air position when the actual Ground position is V. Hence the true Wind has blown from D to V in 9.2 minutes, a distance of 5.6 n.m. from 072° T. The true Wind Velocity is therefore $072^\circ/37$ k. It may be remarked that in the present example, DA need not be drawn or measured.

51. The relative Wind may be used directly in determining the surface Wind Velocity, provided that the Navigator knows the speed of the ship which he proposes to use as a moving datum. This knowledge may often be assumed from a consideration of the type of craft, and the bow wave, or the wake, that it is making.

Example:—

52. A ship is observed by bearing compass to be steering a Track of 040° T.

The wind lanes are observed to bear 000° T and 180° T, while smoke is observed leaving the ship in a direction of 330° T.

The ship appears to be "making" 10 k approximately.

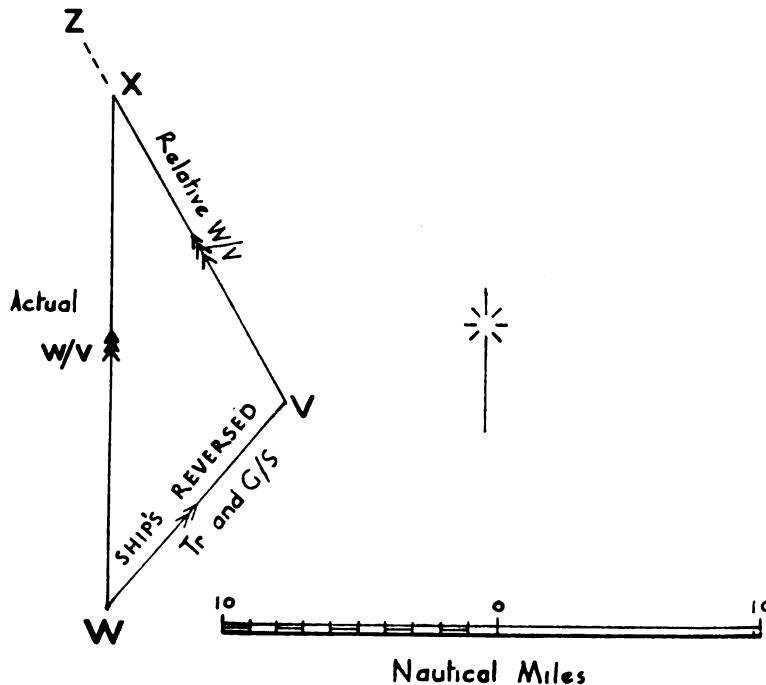


FIGURE 21. Wind-finding: Relative Wind.

53. Lay off VW to represent the ship's Track and Ground Speed reversed. This is one component velocity of the relative Wind Velocity, whose direction is that of the smoke.

From V, lay off VZ in a direction of 330° T.

From W lay off a line in one of the directions of the Wind, to cut VZ at X. VX in length represents the relative Wind Speed, to scale.

Then WX in length represents the true Wind Speed, to scale.

The true Wind Velocity at the surface is therefore $180^\circ/19$ k.

Estimation of Wind Velocity Over Water

54. The Wind Velocity may often be estimated with a high degree of accuracy by an expert Air Navigator, particularly when flying over the sea. By exercising acute observation while in flight, an Air Navigator will in time acquire a wealth of experience, constituting almost a sixth sense, which enables him to judge within small limits the speed and direction of the Wind from the appearance of the sea or from other phenomena beneath him. Use of the landing lights turned on to the sea at night is often to be recommended.

The surface of the sea, disturbed by the Wind, gives a faithful indication of the surface Wind itself. In the method described in paragraph 25 above, the surface Wind Direction was described as being that of the *wind lanes*, those streaks that are clearly visible on the surface of the sea except in the lightest of Winds. Wave systems are not themselves a good indication of Wind Direction, since they are built up over some considerable period of time.

However, much can be told from the waves themselves. A glassy sea indicates a surface calm that may, it is true, belie conditions at operational heights. Yet when the Wind is strong enough to ruffle the sea, it will generally be sufficiently related to the Wind at operational height to be a reliable index of the latter.

55. The following tabulated speeds of the surface Wind are closely related to various distinctive sea phenomena.

Surface Wind Speed		Surface Phenomenon
At 10 k		Appearance of foam.
At 15 k		Appearance of dispersed white caps.
At 20 k		White caps become continuous.
Above 20 k		Sea has a distinctly rough appearance.
At 35 k		Foam is blown in streaks from the crests of white caps.

The Navigator must bear in mind the relation between the surface Wind and upper Winds that has already been alluded to in paragraph 25 above with regard to both speed and direction.

Estimation of Wind Velocity Over Land

56. Over the land, a good indication of the Wind is afforded by a study of cloud movements. From the ground the Navigator may estimate the Wind Velocity he will experience on departure by examining the movement of the clouds overhead. Where two or more layers of clouds are discernible, showing individual movements, a height may often be chosen that will give the most favourable Wind for the ensuing flight.

The reverse process is also possible : The shadows of clouds move with the clouds across the ground. The clouds may be at the same height as, or above or below, the aircraft. In any case the movement of the shadows can often be clearly judged from the air against the features of the ground. It is then possible to check the Wind Velocity at the level of the clouds by watching the cloud shadows. On occasions when advance meteorological information is not readily available, the Navigator will find such a study valuable during a flight over featureless or badly-mapped country. Even though the exact Wind Velocity is not obtained, the aircraft may often be satisfactorily flown at the height of the most favourable Wind by intelligent observation.

The Effects of Changes in Wind Velocity

57. Changes in Wind Velocity may be changes in Direction, or in Speed or in both together. For the purposes of analysis, the changes are considered separately and the Winds are also considered under the four principal groups, viz., Head Winds, Tail Winds, Beam Winds and Quadrantal Winds. In each of the following cases the True Airspeed is taken to be 180 k, and the Wind Speed 30 k, the changes therein being in the order of ± 10 k.

(i) Head Winds

(a) Change of Direction

It will be seen from Figure 22 (a) that changes in Wind Direction have practically no effect on Ground Speed but have an immediate effect upon the drift. In other words, alterations of Course in a Head Wind will cause large alterations of Track, but the Ground Speed will not change much.

(b) Change of Speed

It will be seen from Figure 22 (b) that Changes of Wind Speed have a direct and inverse effect upon Ground Speed, while drift remains practically unchanged. In other words, an alteration of True Airspeed will have a directly proportional effect upon Ground Speed when flying in a Head Wind.

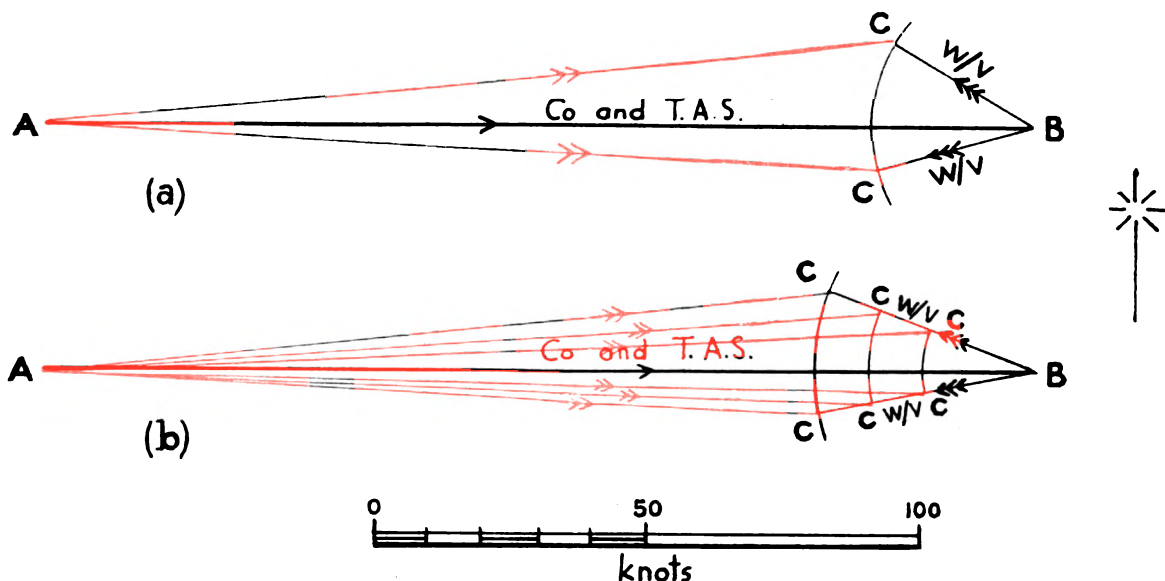


FIGURE 22. Changes in Velocity of Head Winds.

(ii) **Tail Winds**(a) *Change of Direction*

It will be seen from Figure 23 (a) that changes in Wind Direction have little effect on Ground Speed, while the effect on drift is considerable (though not so much as in (i) (a) above). It follows that changes of Course in a Tail Wind cause large changes of Track, while the Ground Speed remains about the same.

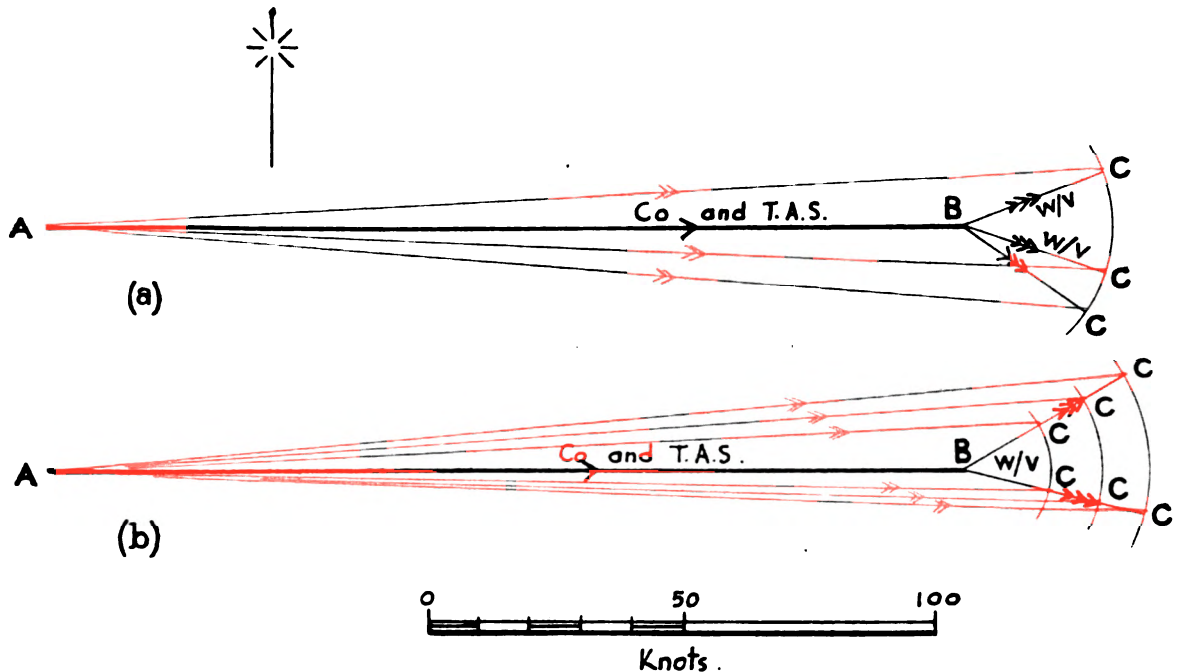


FIGURE 23. Changes in Velocity of Tail Winds.

(b) *Change of Speed*

It can be seen from Figure 23 (b) that changes of Wind Speed have a directly proportional effect upon Ground Speed, while drift remains practically unchanged. It follows that changes of True Air-speed have a directly proportional effect upon Ground Speed in a Tail Wind, without affecting the Track.

(iii) **Beam Winds**(a) *Change of Direction*

From Figure 24 (a) it can be seen that changes of Wind Direction on the beam have almost no effect upon drift, while the Ground Speed is considerably affected. It follows that changes of Course in a Beam Wind have a large effect on Ground Speed, while the Track will change by the same amount as the Course.

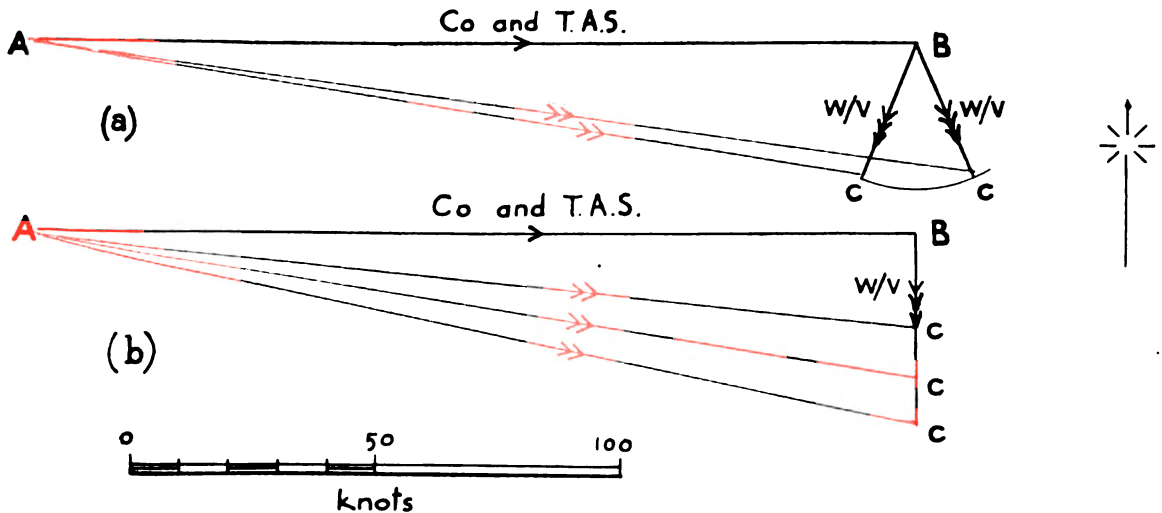


FIGURE 24. Changes in Velocity of Beam Winds.

(b) *Change of Speed*

It can be seen from Figure 24 (b) that changes of Wind Speed on the beam have little effect on Ground Speed but are reflected in considerable changes of drift. It follows that when drift is observed to change substantially in a Beam Wind, the strength of the Wind is more likely to have altered than the Wind Direction.

(iv) **Quadrantal Winds***Change of Direction or Change of Speed*

It can be seen from Figures 25 (a) and (b) that changes in either Wind Direction or Speed affect both drift and Ground Speed. It follows that in Quadrantal Winds, if Course is altered, both Ground Speed and Track will change.

58. The following generalisations can now be made in conclusion, and it is obviously unwise for the Air Navigator who observes no change in drift or Ground Speed to conclude that the Wind has not changed.

(i) *No change in Drift observed* is consistent with :—

(a) *Head Wind or Tail Wind* : Speed of Wind may have varied considerably, having large effect on Ground Speed

(b) *Beam Wind* : Direction of Wind may have changed, having large effect on Ground Speed.

(c) *Quadrantal Wind* : A possible change in both the Direction and Speed, since change of Speed alone or Direction alone affects both drift and Ground Speed.

(ii) *No change in Ground Speed observed* is consistent with :—

(a) *Head or Tail Wind* : Possible change in Direction of Wind, having large effect on drift.

(b) *Beam Wind* : Possible change in Speed of Wind, having large effect on drift.

(c) *Quadrantal Wind* : A possible change in both Speed and Direction of the Wind, since a change in either of the components would affect both drift and Ground Speed.

(iii) *Altering Course to make good a new Track* :—

(a) In a *Head Wind or Tail Wind*, a small alteration will result in a big change of Track.

(b) In a *Beam Wind*, the alteration of Course causes an equal alteration of Track.

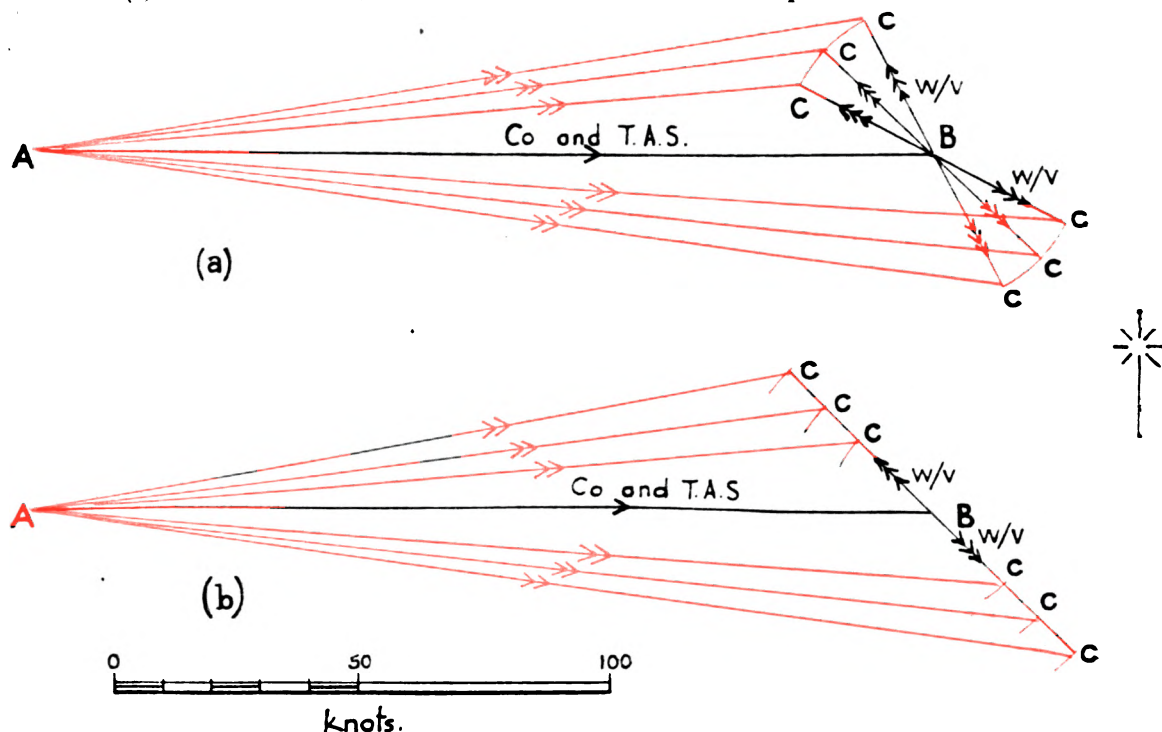


FIGURE 25. Changes in Velocity of Quadrantal Winds.

59. The above conclusions are summarised under the four main directions of the Wind relative to the aircraft's head.

GENERAL DIRECTION OF WIND.	WIND, CHANGE OF.	EFFECTS.	
		ON GROUND SPEED.	ON DRIFT.
(a) Head	Direction.	Very small.	Very big.
	Speed.	Very big.	Nil.
(b) Tail	Direction.	Small.	Fairly big.
	Speed.	Very big.	Nil.
(c) Beam	Direction.	Very big.	Nil.
	Speed.	Small.	Very big.
(d) Quadrantal ..	Direction.	Moderate.	Moderate.
	Speed.	Moderate ; more pronounced with Quarter Wind.	Moderate ; more pronounced with Bow Wind.

Finding Position by Dead Reckoning

60. In the preceding paragraphs the methods used by the Air Navigator to analyse and measure the separate velocities that contribute to his progress over the ground have been examined. There remains one other general problem to solve, namely, the calculation of position. The process by which the Track, Ground Speed and position of an aircraft may be calculated is known as *Dead Reckoning*. The Navigator should at any time be able to calculate his whereabouts from what has already occurred during the flight.

61. The *D.R. Position* is, however, always open to doubt, and is consequently rather a misnomer. If the previous observations have been inaccurate, it follows that the calculations based upon them will be inaccurate. There is, moreover, an assumption, which is by no means true, that what has happened on one stage of the flight will also happen upon another. Conditions of flight unfortunately do not remain stable, and the more they fluctuate, the further will be the D.R. position from the actual position of the aircraft, though fluctuations may and often do cancel each other.

62. The principle underlying the calculation of the D.R. Position is that as the Air Position of the aircraft can be worked out from observations of True Course, True Airspeed and the Time, then if the Wind Velocity is known and the appropriate Wind Effect is applied to the Air Position, the Ground Position of the aircraft is determined. This principle may be applied in the two following ways :—

(i) *When Track and Ground Speed are observed.*

The Navigator observes that his aircraft has travelled from A to C (Figure 26) in n minutes. Without elaborate calculation he can assume that after another n minutes the aircraft will have reached X, such that CX equals AC.

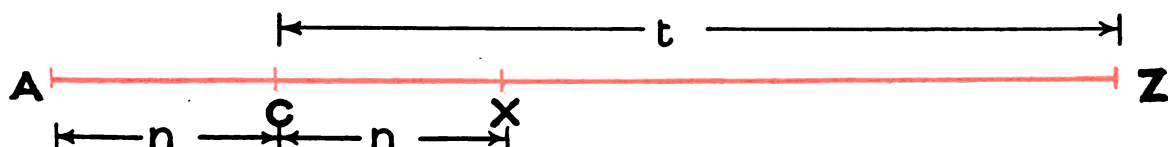


FIGURE 26. D.R. Positions.

With the aid of Time and Speed scales, or by calculating the Ground Speed ($\frac{60 AC}{n}$ units per hour) the Navigator may determine the distance CZ, travelled along AC produced, for any time interval t minutes, since the distance will be proportional to the time. That is, $CZ : AC :: t : n$.

X and Z are in fact D.R. positions of the aircraft.

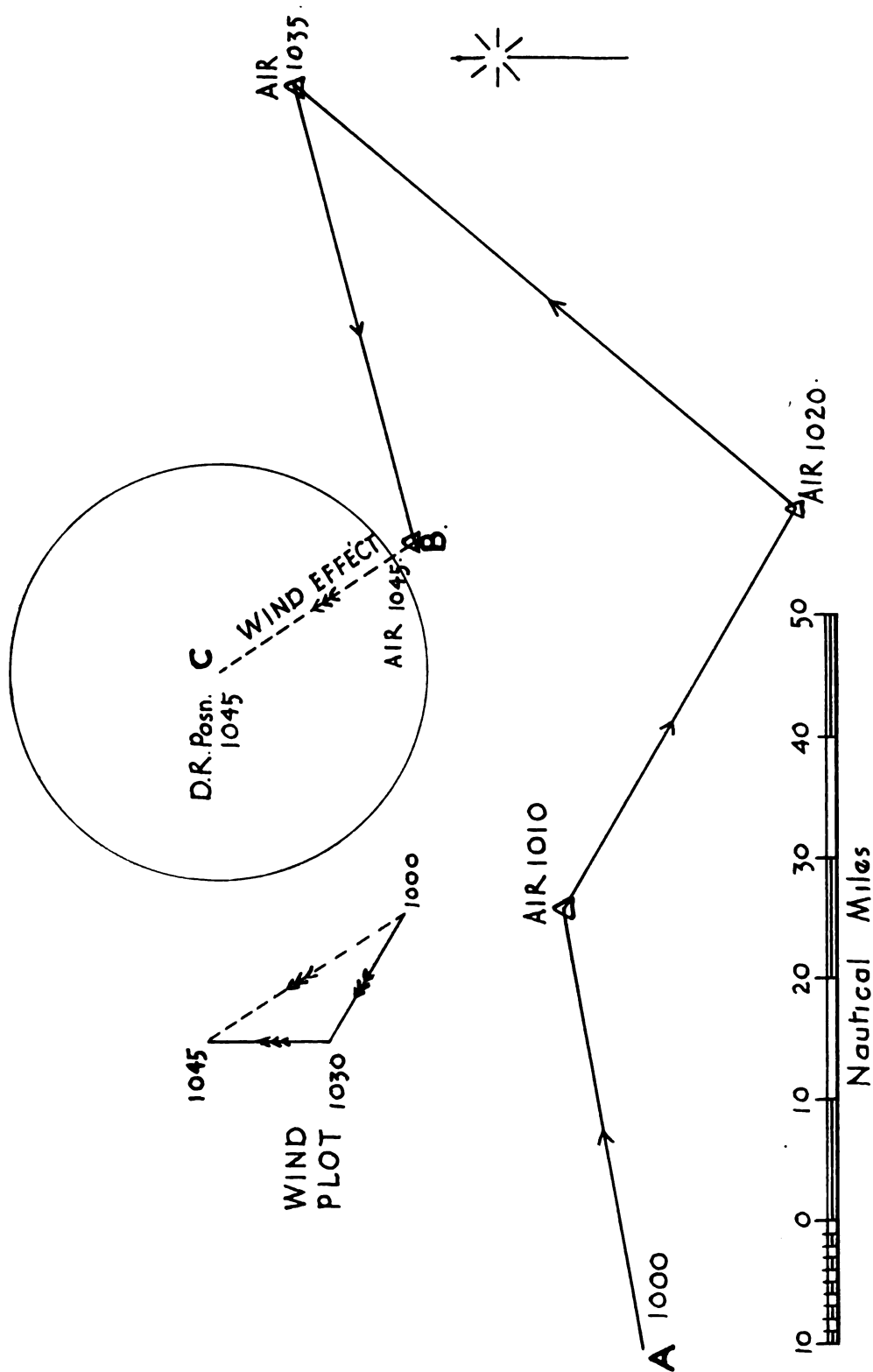


FIGURE 27. Air Plot for D.R. Position.

This process is very often adopted in practice when the aircraft maintains a constant True Airspeed, Course and height, and no change of Wind is experienced. As soon as any material conditions of flight change, such simple calculations become impossible.

(ii) *The Air Plot.*

During operational flying it may be necessary to alter Course, True Airspeed and height frequently. Opportunities for observing position may not be readily available, or when a fix is obtained, its application to further calculation may be made obscure by subsequent changes in True Airspeed, Course and height. Yet provided the Navigator keeps an accurate check of the Time, the Courses, True Airspeeds and heights of the aircraft, and provided he knows the Wind Velocity for the various stages and heights of the flight, he can reconstruct a *D.R. Position* at any time.

63. An Air Plot consists of laying down Courses and their respective air distances, assuming a complete absence of Wind. Any point on the Air Plot is an imaginary "air position." By taking his air position at the time of his required D.R. position, and laying off from it a distance representing the total calculated effect of the Wind since the commencement of the Air Plot, the Air Navigator will obtain a "D.R. position," the accuracy of which depends upon his knowledge of the actual Courses, True Airspeeds, and Wind Velocities experienced.

The error of the D.R. position due to accumulated inaccuracies of data and erroneous plotting may amount to as much as 10 per cent. of the air distance flown *from a previously known ground position* of the aircraft. The activities of the Air Navigator should be constantly directed towards keeping this possible 10 per cent. error within narrow *absolute* limits, by fixing position positively as frequently as he can and restarting the Air Plot from each definite fix.

64. *Example.* The log of an Air Navigator reads as follows :—

Time	Course ° (T)	Course ° (M)	Observations.
10.00	080	090	Posn. " A " S/C T.A.S. 220 k Ht. 2,000 ft.
10.10	120	130	A/C
10.15			T.A.S. 240 k
10.20	040	050	A/C, climbing at T.A.S. 200 k
10.30			Level at 8,000 ft. T.A.S. 250 k
10.35	265	275	A/C

The Navigator calculates the Wind at 2,000' ft. to be $120^{\circ}/24$ k and at 8,000 ft. to be $180^{\circ}/40$ k.

Required to find the D.R. Position at 10.45 hours. (See Figure 27.)

Having regard to changes of True Course and True Airspeed, the successive air positions are plotted, and against each turning point the time and word "AIR" are written. By 10.45 hours the aircraft can be considered as having been affected by Winds of $120^{\circ}/24$ k for 30 minutes, and $180^{\circ}/40$ k for 15 minutes. This is only approximately true, for a sudden change at 10.30 hours would not have taken place. Laying off these two Winds in correct proportions from the air position B, at 10.45 hours the D.R. position at 10.45 hours is obtained at C.

The total air distance flown is 171 n.m. ; consequently the position of the aircraft, if not actually at the D.R. position, is at least likely to be somewhere within a circle drawn with centre C and radius (10% of 171 n.m. =) 17 n.m., as shown.

65. The effect of the Wind which must be applied can most easily be found if a separate plot is kept for this purpose. The Winds are laid off in succession, as they are experienced, and when the D.R. position is required, the Wind effect is measured from the start of the *Wind Plot* to the point on the latest Wind corresponding to the required time. This method is illustrated in Figure 27.

Note.—An Air Plot is ALWAYS made using TRUE Courses.

Correcting a D.R. Position for a Wrong Wind Used

66. If a Navigator should find that the wrong Wind Velocity has been used on a flight, and he wishes to make suitable allowance in his plot, the *correction vector* between the incorrect and correct Winds should be found, and this correction applied to the wrong D.R. position.

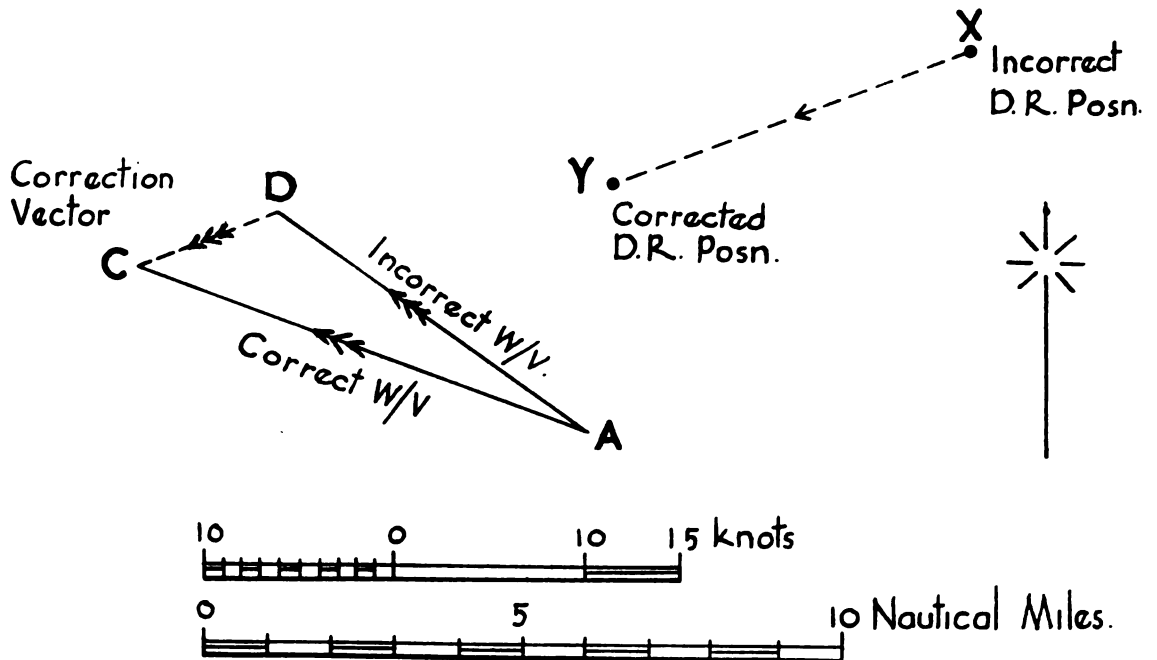


FIGURE 28. Correcting a D.R. Position.

The two Wind vectors should be laid off down-wind from a common air position, A in Figure 28, and the correction vector is expressed as a velocity, *from* the incorrect ground position D, *to* the correct ground position C.

Example:—

67. A Navigator assumes that the Wind Velocity is $125^{\circ}/20$ k. After a flight of 45 minutes, the Wind is found to be $110^{\circ}/25$ k.

Suppose the wrongly assumed D.R. position is at X.

By vectoring the two Wind Velocities as described, the Correction Vector is found to be from $069^{\circ}/8$ k.

In 45 minutes, the amount of correction to apply would be only $\frac{3}{4}$ of 8 n.m., i.e., 6 n.m.

From X lay off XY, a distance of 6 n.m., from a direction of 069° T.

Then Y is the corrected D.R. position.

Correcting a Wind Used by Finding the Error in a D.R. Position

68. When the Navigator obtains a fix which does not agree with his D.R. position, and the plotting is above suspicion, the error is due to an incorrect Wind having been used, or to a change in the Wind experienced during flight.

In either case the Wind used should be corrected preferably by finding a new Wind. It can also be done by finding a Correction Vector which may be applied to the wrong Wind to produce the correct, or at least a more correct Wind. The Correction Vector is found by measuring the direction and distance from the D.R. position to the fix, and expressing it as a velocity.

If the Wind has been changing over the period of flight, as will be the case on any but the shortest flight, the Wind Velocity so found will only be the *mean Wind* experienced.

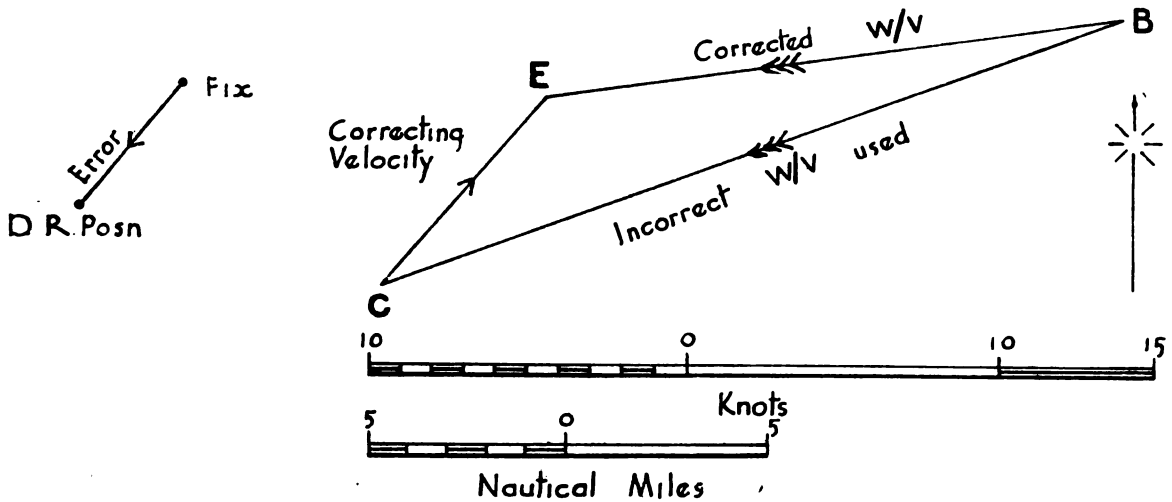


FIGURE 29. Correcting a Wind.

Example:—

69. After 30 minutes, the error in a D.R. position is found to be 4 n.m. in a direction of 220° T. The Correcting Velocity will therefore be $040^\circ/8$ k. (See Figure 29.)

Lay off BC to represent the original Wind, say $070^\circ/25$ k, used when calculating the D.R. position.

From C draw CE to represent the Correction Vector, $040^\circ/8$ k.

Then BE represents the corrected Wind Velocity, which is found to be $082^\circ/18\frac{1}{2}$ k.

CHAPTER VI

POSITION LINES

"I wonder if all the things move along with us?" thought poor puzzled Alice.

—ALICE THROUGH THE LOOKING GLASS.

How Position Lines are Obtained

1. A position line is a line drawn on a map or chart at some point upon which the aircraft is known to have been at a particular time. A position line can be obtained in any of the seven following ways by making either a visual or a radio observation of a known object, hereinafter called the "origin."

2. By observing two origins in Transit (i.e., in line with the Navigator) a position line is obtained simply by producing the line joining the origins. The accuracy of this method is probably as high as $\pm \frac{1}{2}^\circ$. The line indicates the centre of a sector of position about 1° wide, anywhere in which the aircraft may be.

Example :—

3. A Light Vessel and a Castle are observed in transit at 12.20 hours. Figure 1 shows the position line drawn in the vicinity of the estimated position of the aircraft. The broken line need not be drawn. The transit would be recorded in the log as "12.20 hours Lt.V. ø Castle."

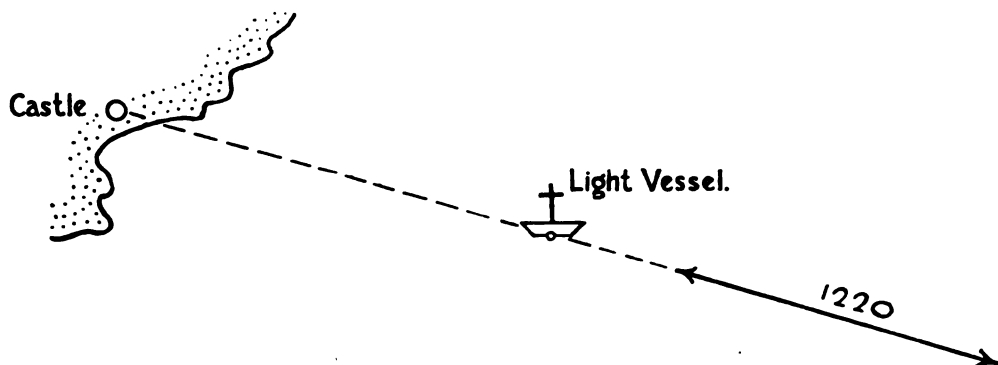


FIGURE 1. Light Vessel ø Castle 12.20 hours.

4. *By Compass Bearing.*—If the compass bearing of an origin is obtained, and Deviation (for magnetic Course of the aircraft) and Variation are applied to convert the bearing to True, the reverse of the True bearing, drawn from the origin, may be regarded as a position line. The accuracy of such a bearing will be no better than $\pm 2^\circ$, and will often be far worse. Thus the *sector* of position will be at least 4° wide in average conditions.

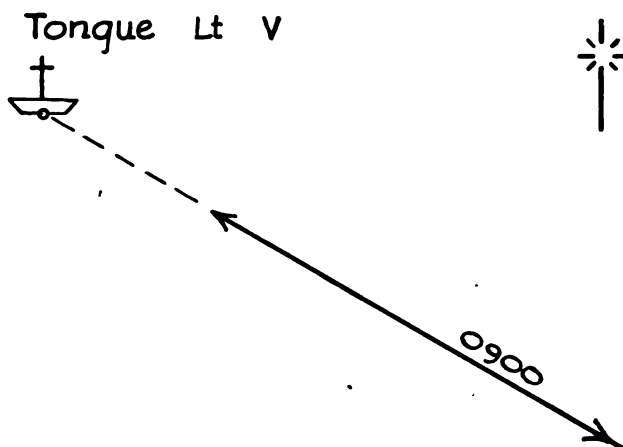


FIGURE 2. Position Line by Compass Bearing.

Example :—

5. An aircraft was proceeding on a Course of 040° M, and the Tongue Lightship was observed bearing, say, 315° C at 09.00 hours. Deviation was, say, -5° , Variation, 10° W; then the True bearing was $(315^\circ - 5^\circ - 10^\circ =) 300^\circ$ T. It can be said that at 09.00 hours the aircraft was on a bearing of $(300^\circ \text{ T} \pm 180^\circ =) 120^\circ$ T from the lightship. Figure 2 shows the position line at 09.00 hours.

6. *By Relative Bearings.*—If the horizontal angle between the aircraft head and an origin is measured by a D/F loop, an astro compass, a bearing plate, a pelorus or by observation down the leading or trailing edge of a wing, and if the True Course of the aircraft is applied, then the reverse bearing, laid off from

the origin, is a position line. The accuracy of this bearing will not be better than $\pm 2^\circ$, so that here again the aircraft may be anywhere within a *sector* of position at least 4° wide.

Example :—

7. At 09.05 hours, while on a Course of 330° T, the Tongue lightship was observed on the starboard beam (i.e., " 90° Green"). The bearing was therefore $(330^\circ \text{ T} + 90^\circ) = 060^\circ \text{ T}$, and the position line would be drawn as the reverse of this, namely $(060^\circ \pm 180^\circ) = 240^\circ \text{ T}$ from the Tongue lightship. (See Figure 3.)

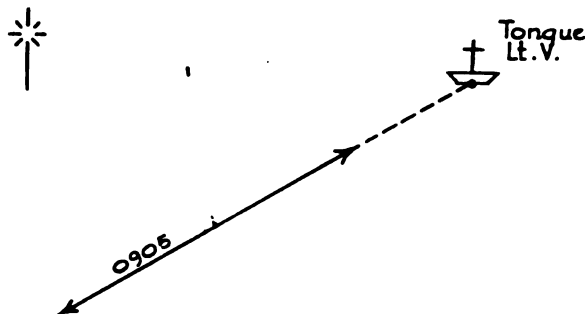


FIGURE 3. Position Line by Relative Bearing.

8. By *Astronomical Observations* it is possible to obtain a position line, as explained in Chapter VII. Such observations require more skill than those already described. Such a position line may be considered in average conditions to indicate the centre of a *band* of position some 10 miles wide, anywhere in which the aircraft may be. The width of the band depends upon the skill of the observer, the accurate maintenance of straight and level flight during observation, and the precision of the instruments used.

9. By a *D/F W/T*, the True bearing of an aircraft from a D/F station may be obtained and communicated to the Navigator, together with the time of observation. This bearing is probably accurate to within $\pm 2^\circ$ if a first class bearing, or if a second class bearing, to within $\pm 5^\circ$. A third class bearing may be more than $\pm 5^\circ$ in error. The width of the *sector* of position varies upwards therefore from 4° to more than 10° .

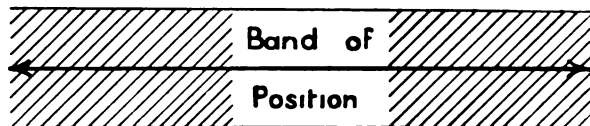


FIGURE 4. The Astronomical Position Line.

10. By a *Plan Range*.—If the plan range of an origin is observed from an aircraft, the circumference of a circle drawn with centre the origin and radius the range may be regarded as a position line. No very accurate measurements of range can at present be made, and the aircraft may therefore be within a *band* of position either side of the position line.

Example :—

11. A Navigator measures the range of landmark A at 10.00 hours, and finds that it is 10 n.m. The position line is illustrated in Figure 5.



Use of Single Position Lines

12. It often happens that the Navigator can obtain only a single position line. Since the aircraft may be anywhere upon this line, its value by itself is restricted to the following rather specialised contingencies.

(i) *Confirming Track by a Single Position Line*

If the Navigator obtains a position line that is parallel, or nearly parallel, to his Track, the position line will serve to indicate, within its limits of accuracy, whether he is on his desired Track or to one side of it.

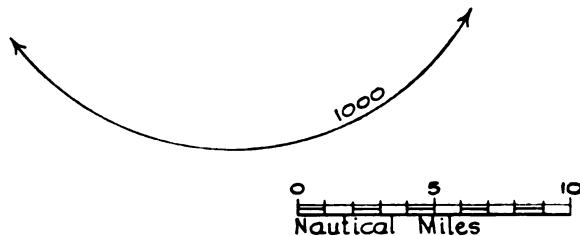


FIGURE 5. Position Line by Plan Range.

Figure 6 shows a position line at 11.15 hours, that confirms the Track of the aircraft.

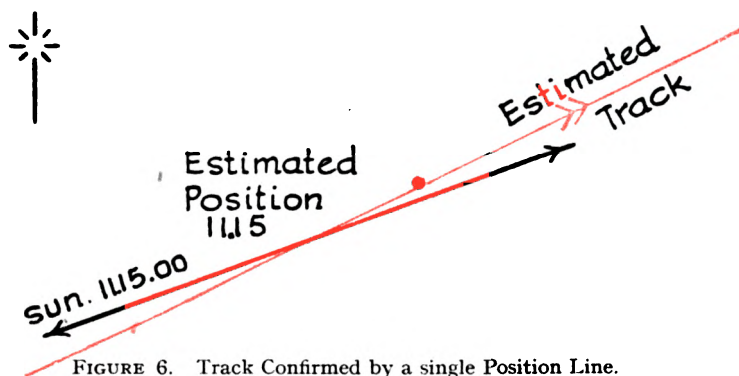


FIGURE 6. Track Confirmed by a single Position Line.

(ii) *Finding Ground Speed by a Single Position Line*

If the Navigator obtains a position line that is nearly at right-angles to his Track, the Ground Speed may be calculated from the distance run between his last known position and the intersection of his D.R. Track and the position line.

Figure 7 shows an aircraft that left point A at 13.00 hours on a D.R. Track, AX.

A position line was obtained at 13.30 hours, as illustrated, cutting AX at B.

It will be seen that if the Track was much as 10° in error, such that AY represents the *actual* Track of the aircraft, the Ground Speed calculated from the run AB will not differ appreciably from that calculated between A and C, the actual position of the aircraft at 13.30 hours.

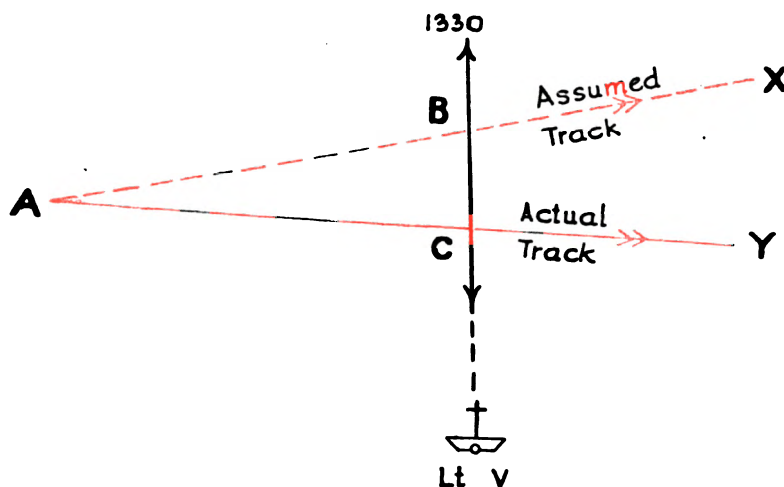


FIGURE 7. Ground Speed by a Single Position Line.

(iii) *Homing by a Single Position Line*

(a) *When the position line passes through the destination*

This possibility may arise if a position line is obtained with the destination as its origin, e.g., a Q.D.M.*; in which case the Course must be adjusted to make good the Track down the position line. It is however essential to know on which side of the origin the aircraft is situated.

A typical case is illustrated in Figure 8, where a D/F bearing from an aerodrome A is passed to the Air Navigator. To reach A, the aircraft must be steered on a Course to make good a Track which is the reverse of the D/F bearing, making suitable allowances for Drift.

* The Magnetic Course to steer to reach a place is prefixed by "Q.D.M." in the "Q" Code.

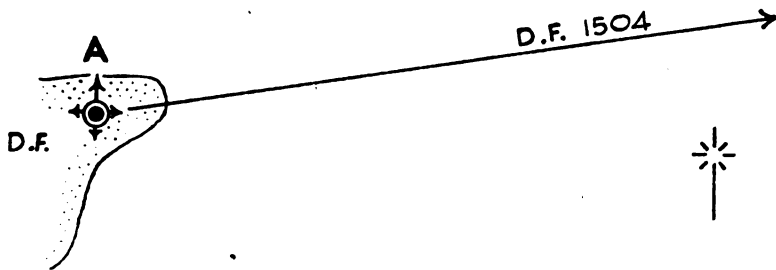


FIGURE 8. Homing by a Single Position Line.

(b) *When the position line does not pass through the destination*

This may arise when the destination is not the origin of the position line. When the visibility or the destination is sufficiently extensive to compensate for any possible error in the position line, the latter should be used as follows :—(See Figure 9.)

The Navigator estimates the maximum possible error to which he considers himself liable. With centre his D.R. position and radius the maximum possible error, an arc is described cutting the position line on the side inclined towards the destination. From this point (A in Figure 9) a line is drawn to the destination, H.

The aircraft is then steered to make good a Track and distance, AH, i.e., the run between the point on the position line and the destination. Should the destination not be sighted after completing this Track and distance, the aircraft should be turned to make good, by drift observations or by D.R., a Track along the position line transferred* through the destination, H. Since the aircraft has been deliberately placed on one side of the destination, no mistake will be made in turning the wrong way after the run up to the transferred position line.

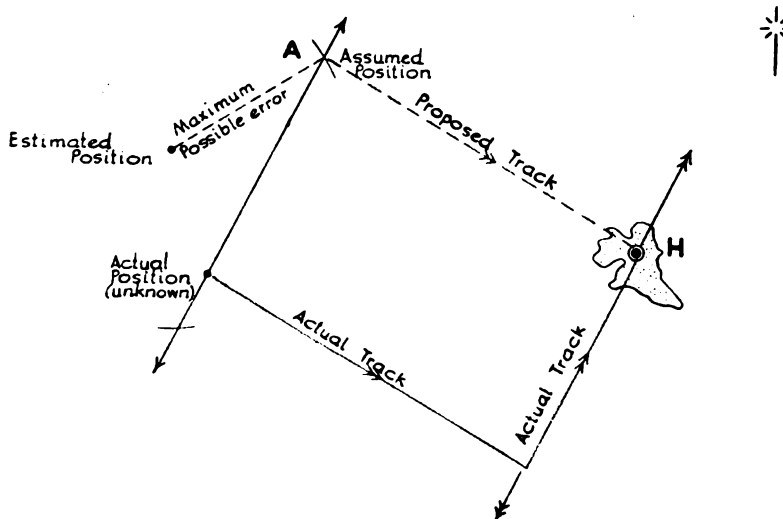


FIGURE 9. Homing by a Single Position Line.

Provided the position line is obtained within one hour of the Estimated Time of Arrival, it is not considered that errors in the run will appreciably affect the final Track to the destination. If, however, the visibility is less than the possible width of the band of position (see paragraph 8) or if the destination is small in area, the latter may be passed on either side of the final Track without being seen, and other steps must be taken to find it.

* The full implications of transferring position lines are discussed in paragraphs 22, 23 and 24.

Use of Multiple Position Lines

13. If more than one position line is available at any instant, the position of the aircraft may be fixed with a certainty which depends on the accuracy of the position lines and their inclination to one another. Take, for example, the two position lines in Figure 10.

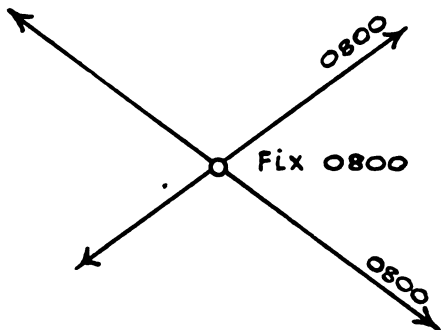


FIGURE 10. Fix by Simultaneous Position Lines.

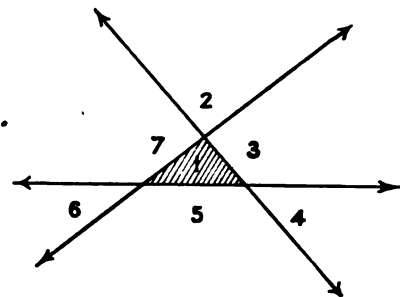


FIGURE 11. A Cocked Hat.

By definition, at 08.00 hours the aircraft is situated somewhere on both lines. Since their point of intersection is the only position common to both, it must therefore be the *fix* of the aircraft at 08.00 hours.

The Cocked Hat

14. It is most improbable that, if more than two position lines are available, they will intersect at one single point, since the bearings are subject to the errors as already indicated. Moreover, the further most position lines are extended away from their origins, the greater will be the actual error. Any three position lines probably form a small triangle, which is called a *Cocked Hat*. (Figure 11.)

15. If the errors of the bearings, from which the position lines are obtained, are all of the same *sign*, it can be seen from Figure 12 that the actual position of the aircraft may be *outside* the cocked hat. In the example illustrated, the bearings measured by the Navigator were all 2° too small, and are indicated by broken lines. The unbroken lines represent the correct bearings.

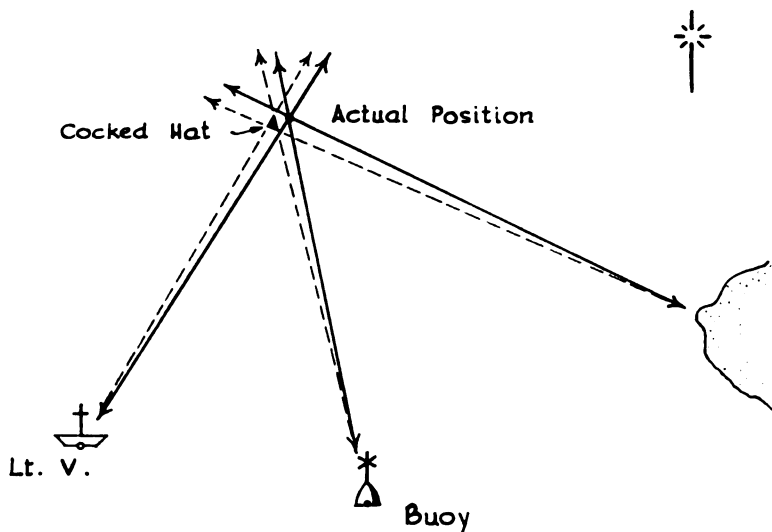


FIGURE 12. The Cocked Hat as a Fix.

16. It is more often the case that errors in measurement are quite haphazard, and hence the Navigator cannot tell which of the seven possible positions in Figure 11 contains the actual position of the aircraft. For this reason the *centre of the cocked hat* is assumed for all *practical purposes to represent the fix*, provided the sides of the cocked hat are not excessively long. The larger the cocked hat, the less reliable is its centre as a fix. It should be noted that absence of a cocked hat does not denote

perfect accuracy. In Figure 13 the actual position of the aircraft was at A ; yet an incorrect position B was obtained by the exact intersection of three erroneous bearings at 15.00 hours, as shown.

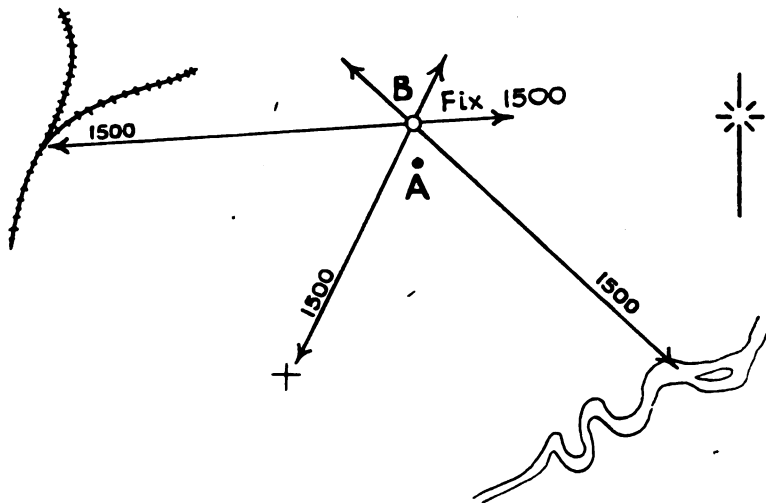


FIGURE 13. Fix from Three Incorrect Position Lines.

Fixes may be obtained from position lines in the ways described in the following paragraphs.

Range and Bearing Fix

17. If, while observing the bearing of an origin, its plan range from the aircraft is also measured (e.g., by Plan Range-finder or by other means) the position of the aircraft may be fixed. Accurate measurement of plan ranges is very difficult in practice. Figure 14 represents a range and bearing fix, A, at 12.00 hours, which is expressed as 100° Tongue Lt. V. 5'.

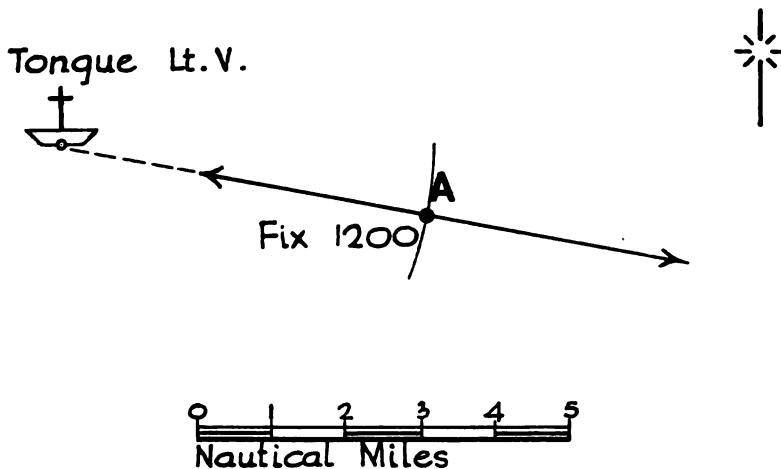


FIGURE 14. Range and Bearing Fix.

Fix by Simultaneous Bearings

18. If the Navigator is able to take an instantaneous bearing of two or more origins, the intersection of the plotted position lines constitutes a fix, since it is the only point in common to the several lines drawn.

19. The greater the angular difference between position lines, the more positive is the fix thus obtained. As a general rule *bearings that differ by much less than 45° from one another should not be used.* No reliance can be placed on a fix when the position lines meet at an angle of less than 30° .

20. When observing two or more origins, the bearings must be very nearly instantaneous if it is desired to neglect the movement of the aircraft, which may travel one mile every 12 seconds or so. The fix is timed at the moment when the origin most nearly on the beam is observed, since its bearing is changing most rapidly.

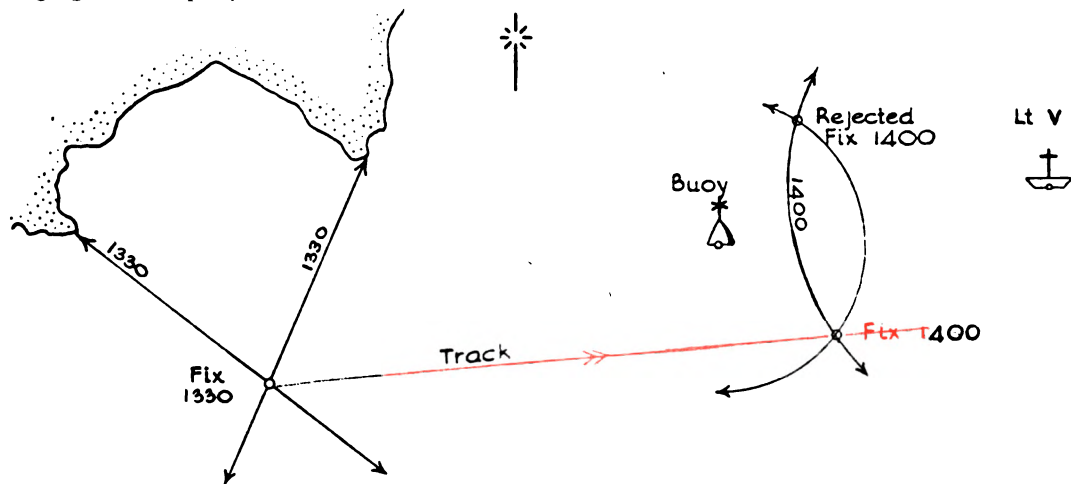


FIGURE 15. Two Fixes by Simultaneous Position Lines.

21. Figure 15 illustrates two fixes obtained from simultaneous position lines. On the left, two simultaneous bearings were obtained at 13.30 hours by bearing compass, and the position lines drawn accordingly from their respective origins. On the right, two ranges were observed by the Navigator at 14.00 hours. The intersection of these position lines gives two fixes, one of which is easily rejected as being inconsistent with the observed relative positions of the aircraft and the origins.

Transferring Position Lines

22. Simultaneous position lines are seldom obtainable in flight. There will usually be a time-interval between them which cannot be neglected, since the aircraft may have moved a considerable distance between successive observations. The difficulty is overcome by *transferring* the position lines. This can be done because a position line is a bearing of the *ground* position of an aircraft from a known origin. Hence, if the origin were moving on a Track parallel with that of the aircraft and at its exact Ground Speed, the bearing of the aircraft from the origin would remain unchanged over any interval of time.

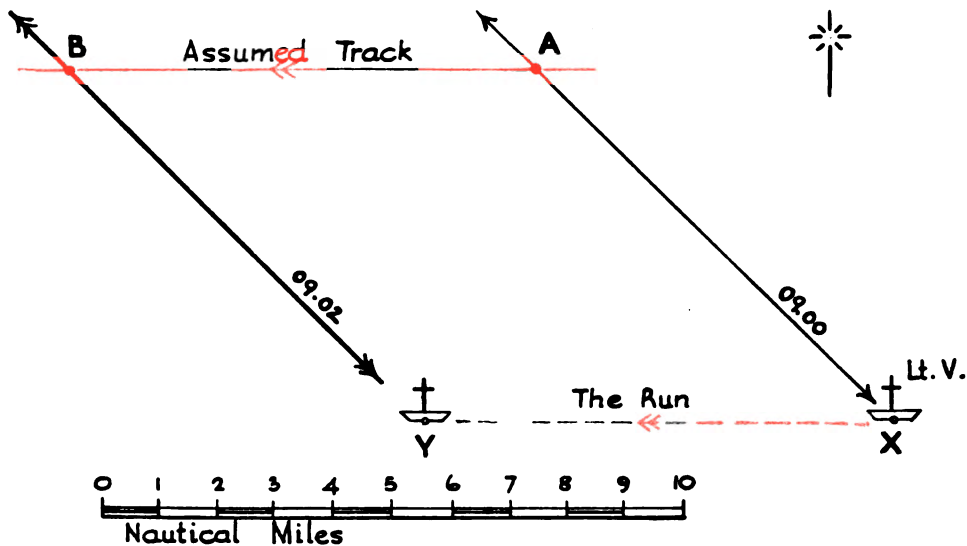


FIGURE 16. Transferring a Position Line.

23. Suppose an aircraft, whose Track is 270° T and Ground Speed 240 k, is in position A (Figure 16) at 09.00 hours. At this moment the bearing of a light-vessel X is observed to be 135° T. By 09.02 hours the aircraft will have travelled a further 8 n.m. along its Track and will be in position B. If the light-vessel is imagined to travel from X to Y, such that XY is equal and parallel to AB, the line joining Y to B will be an imaginary position line, parallel to XA. The distance along the Track AB or XY, is known as the *run*. The imaginary position line, drawn through the aircraft's 09.02 hours position, B, is known as a *transferred position line*, and is **always signified by double arrows**.

In practice the position of the aircraft would be in doubt; but if its Track and Ground Speed were known, any line, representing the run, will serve as a means of transferring the position line.

24. It should be noted that this argument may be usefully extended to cover the case of an aircraft whose Track or Ground Speed, or both, may be altered in flight.

Example :—

25. A Navigator in an aircraft making good a Track of 225° T at a Ground Speed of 180 k, obtains a bearing of a light-vessel, V, of 170° T at 10.00 hours. At 10.10 hours Course is set to make good a Track of 020° T and the calculated Ground Speed increases to 200 k. Figure 17 shows the transferred position line at 10.16 hours, which is obtained as follows :—

Any point P is selected on the position line at 10.00 hours, and PQ is drawn to represent the run from 10.00 to 10.10 hours (30 n.m. in a direction 225° T). A line drawn through Q, parallel to PV, would be the transferred position line at 10.10 hours.

Now from Q (or any other point on the 10.10 line) draw QR to represent the run from 10.10 to 10.16 hours (20 n.m. in a direction of 020° T). Then through R draw a line parallel to the previous position lines. This will be the 10.16 hours transferred position line, for it is imagined that the light-vessel has performed the same evolution as the aircraft. Note that it is unnecessary to draw the transferred position line at 10.10 hours. Also in practice the points P, Q, R are most conveniently chosen on the assumed Track.

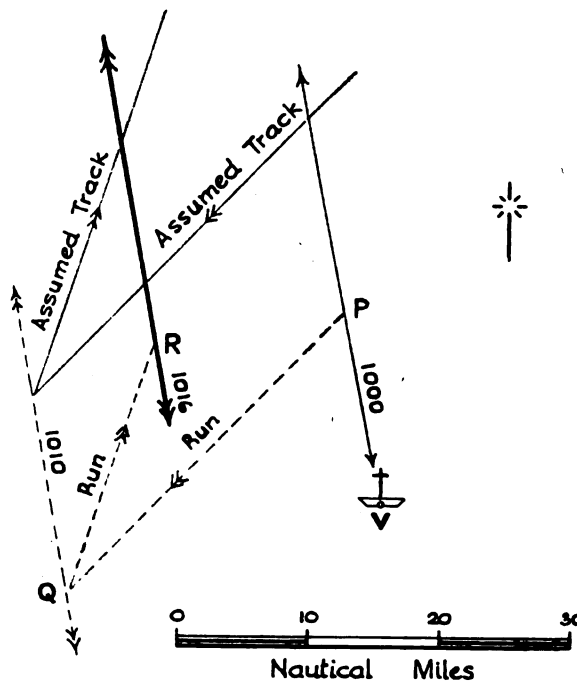


FIGURE 17. Transferring a Position Line.

Running Fix

26. When the position of an aircraft is determined by transferring one or more position lines to cut another position line, the intersection of such lines is known as a "running fix." There are two possibilities :—

(i) *Bearings of Two or More Origins.*

Suppose an aircraft is flying at 150 k on a Course of 260° M and making good a Track of 270° T at a Ground Speed of 180 k. At 11.00 hours a buoy bears 312° C, and at 11.05 hours a light-vessel bears 032° C by bearing compass. Variation is 12° W. Deviation is nil for the bearing compass. The two bearings must first be converted to True, thus :

Time	Bearing (C)	Bearing (M)	Var.	Bearing (T)
11.00	312°	312°	12° W	300°
11.05	032°	032°	12° W	020°

To obtain a fix there must be at least two position lines available at the same instant. Hence one of the position lines must be transferred to the other, as a rule the earlier to the later.

Thus, as in Figure 18, select any point P on the 11.00 hours position line and draw a line PQ equal to the run for 5 minutes (15 n.m. in a direction of 270° T). Through Q draw a line parallel to the 11.00 hours position line, and label it "11.05." The intersection of the two 11.05 hours position lines constitute the fix at that time.

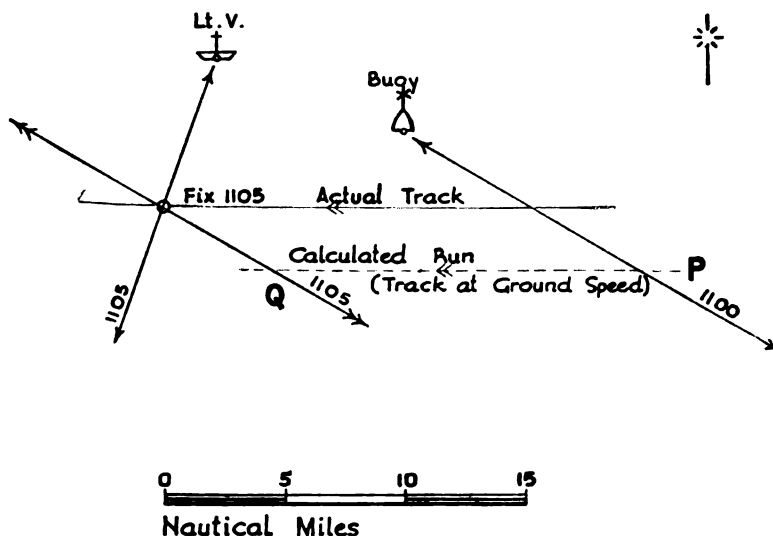


FIGURE 18. Running Fix Using Two Origins.

It must be emphasized that because position lines refer only to *ground positions* they must always be transferred along *Tracks* at *Ground Speeds*. If these are not known, they may be assumed. When the Track and Ground Speed are not known for certain, the accuracy of a running fix is affected, though not seriously, if the time elapsing between successive position lines is reduced to a minimum. Consequently, if nothing definite is known of either, as when flying for long periods above continuous cloud, large errors would not be introduced by the use of Course and True Airspeed as approximations for Track and Ground Speed respectively, provided the position lines are nearly simultaneous.

Using the example just cited, it can be seen from Figure 19 that the fix obtained by transferring the 11.00 hours position line on an assumed run (5 minutes at 150 knots—the T.A.S. in a direction of 248° T—the Course) is not far removed from the actual position obtained from the use of correct data, i.e., it is only 2.5 n.m. from the correct fix. Nevertheless such assumptions should not be made if they can be avoided.

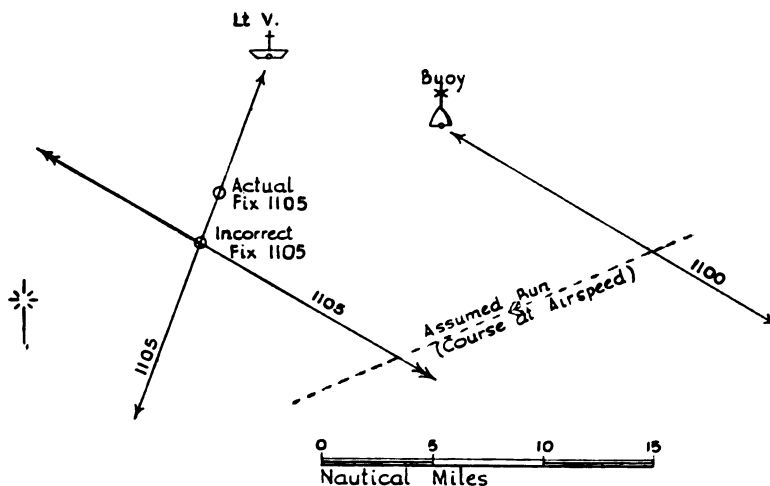


FIGURE 19. Running Fix Using Incorrect Run.

(ii) Bearings of One Origin

The principle of the running fix may be applied when two or more bearings are successively taken of a single origin. The method employed is the same as that used in the previous example, each position line being transferred for its individual run along any line representing the aircraft's Track. Figure 20 represents a fix obtained by three successive bearings of the same origin.

Thus the first position line is transferred along the Assumed Track from A to A', a distance equal to the run in 3 minutes. The second position line is run from B to B', the distance covered in 1 minute. The fix is shown as the intersection of the three position lines at 13.05 hours.

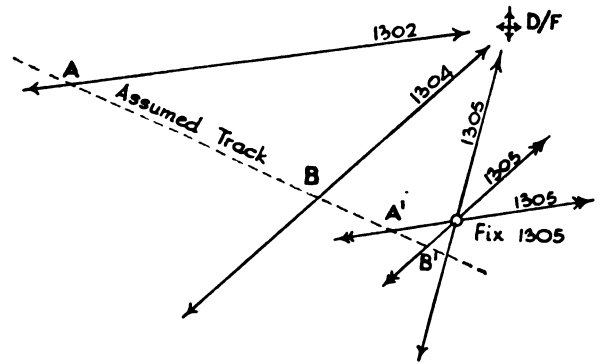


FIGURE 20. Running Fix Using One Origin.

Running Fix with Unknown Track and Ground Speed

27. From the preceding paragraphs it will be seen that if the Track and Ground Speed are doubtful, and the interval between the position lines is large, the fix is likely to be in considerable error. The following method may be used to give an accurate result if an origin is known (such as last reliable fix).

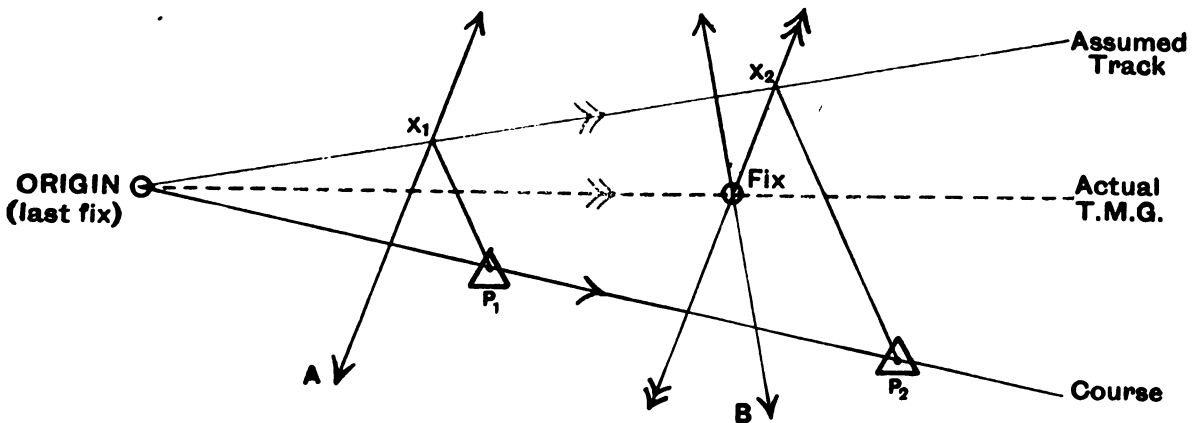


FIGURE 21. Running Fix with Unknown Track and Ground Speed.

Draw in the Course from the last known position, and for the times of the two Position Lines (A) and (B) mark off the respective Air Positions (P_1 and P_2). From the origin, draw in any assumed track cutting the first Position Line at X_1 . Join P_1X_1 and through P_2 draw line parallel to P_1X_1 , cutting assumed track at X_2 (P_2X_2). Then transfer first Position Line (A) through X_2 making fix with Position Line (B). Then this will be the required position. The advantage of this method is dependent on the mean ground speed from the origin, instead of on a more recently found ground speed, generally used when the track made good is known more accurately.

The following are further uses of multiple position lines :—

Finding Track, when Track and Ground Speed are Unknown

28. If three position lines are obtained from one origin, the Track of an aircraft may be found as follows :—

Select a suitable linear scale of time-units, say, 1 minute to 1 cm., and mark off on a ruler, or suitable straight-edge, the number of time-units between the successive position lines.

Doubling the Angle on the Bow

30. This is a special case of a range and bearing fix, and its utility depends on accurate timing and observation. It assumes a knowledge of the Ground Speed, but as has been explained, slight inaccuracies in Ground Speed make no appreciable difference to a fix provided the run is of no great length. The method is as follows:

The time is noted at which an origin makes a chosen angle *with the Track* of between 30° and 80° . The angle on the Bow is observed to increase as the origin is approached and passed. The time when the angle is double the original angle is noted. At this moment the aircraft is a distance from the origin equal to the run between the observations, because the triangle formed by the Track and the two position lines is isosceles.

Figure 24 illustrates a fix obtained by "doubling the angle" of light-vessel A. The first angle observed was 50° at 09.30 hours, and the second angle of 100° was observed at B at 09.32.30 hours. The Ground Speed was 240 k.

B therefore constitutes a fix, 10 n.m. from A.

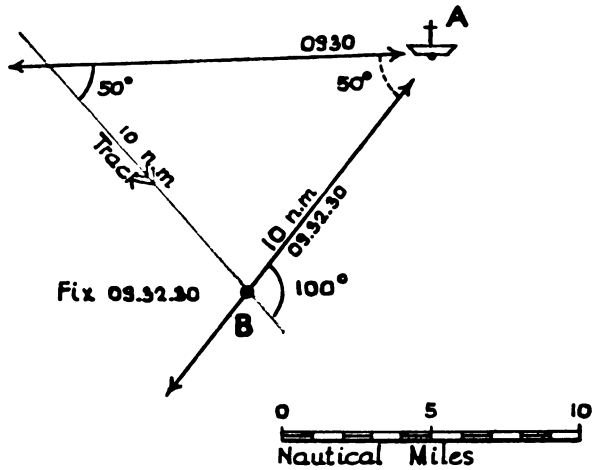


FIGURE 24. Doubling the Angle on the Bow.

Plotting Position Lines

31. So far, position lines have been considered simply as curves or straight lines drawn on paper to represent certain ranges or bearings. It is now necessary to clarify the situation because, as described in Chapter III, the same bearings may be represented in different ways according to the map projection being used.

A position line may be one of three types:

- (i) An Arc of a Great Circle.
- (ii) An Arc of a Small Circle.
- (iii) An Arc of a Curve of Equal Bearing.

An Arc of a Great Circle

32. When a transit is observed, the aircraft is on a prolongation of the shortest line joining the two origins. Since this line must be an arc of a great circle and since only one great circle can pass through any two points that are not diametrically opposed on the Earth, the position line is properly regarded

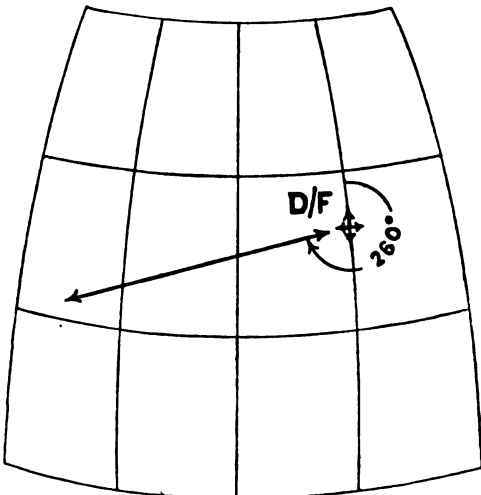


FIGURE 25.

A Great Circle Arc on Topographical Map.

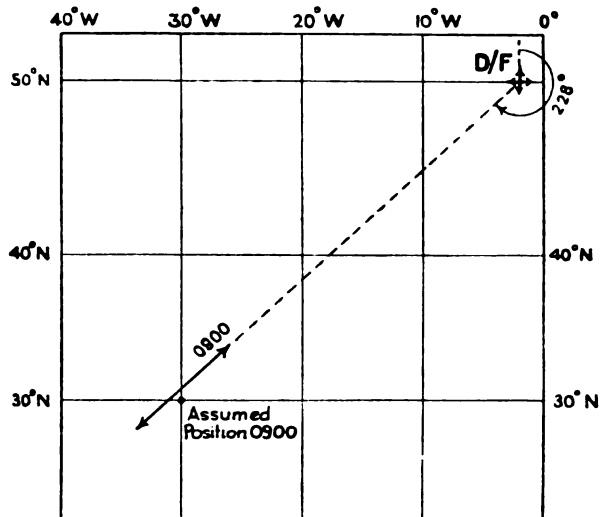


FIGURE 26. A Great Circle Arc on Mercator's Projection Represented by a Rhumb Line.

as an arc of a great circle. Again, when the bearing of an aircraft is measured directly at the origin (e.g., at a D/F station) and subsequently communicated to the Navigator, the bearing measured is a great circle bearing, since wireless waves are assumed to travel along great circles over the Earth. At any origin there can be only one great circle making any given angle with its meridian.

Such a position line properly consists of an arc of the particular great circle drawn from the origin, anywhere upon which the aircraft may be. The plotting of a great circle arc depends upon the projection of the map or chart in use. There are three distinct cases to be considered.

(i) *On all topographical maps*, such position lines are laid off directly from the meridian of the origin as straight lines in the direction of the aircraft, as shown in Figure 25, where the bearing of an aircraft is found to be 260° T at a D/F station.

(ii) *On a gnomonic chart*, the same procedure is followed as for topographical maps. A distorted compass rose applicable to the position of the origin may have to be used.

(iii) *On Mercator's Charts and Plotting Maps*, great circles cannot easily be drawn, owing to their curvature, and the following procedure is adopted in practice :

- (a) Assume a position for the aircraft.
- (b) Calculate the conversion angle. (See Chapter III, paragraph 63.)
- (c) Draw the rhumb line bearing from the origin by applying the conversion angle to the great circle bearing at the origin. A small scale sketch of the situation, with the rhumb line shown always nearer than the great circle to the Equator is the best guide for the application of conversion angle. (See Chapter III, paragraph 75.)

Example :—

33. Suppose an aircraft, whose D.R. position at 09.00 hours is 30° N 30° W, is found to bear 237° T from a D/F station, situated in 50° N 02° W. (See Figure 26.)

The conversion angle is therefore ($\frac{1}{2}$ of $28^\circ \times \sin 40^\circ = 9^\circ$). The rhumb line bearing laid off at the origin will be ($237^\circ - 9^\circ = 228^\circ$ T, and part of this rhumb line is considered to be the position line in the vicinity of the aircraft.

34. It should be observed that the rhumb line in Figure 25 is not strictly the position line, but the inaccuracies of the D/F bearing are likely to be sufficiently large to make further refinement in plotting unwarranted. Should such refinement become desirable with the development of D/F range and technique, the following additional step might be adopted :—

35. Where the rhumb line cuts the estimated meridian of the aircraft, draw a straight line towards the origin, inclined to the rhumb line by the conversion angle already found, on that side of the rhumb line *opposite* the Equator. This represents an arc of the Great Circle position line.

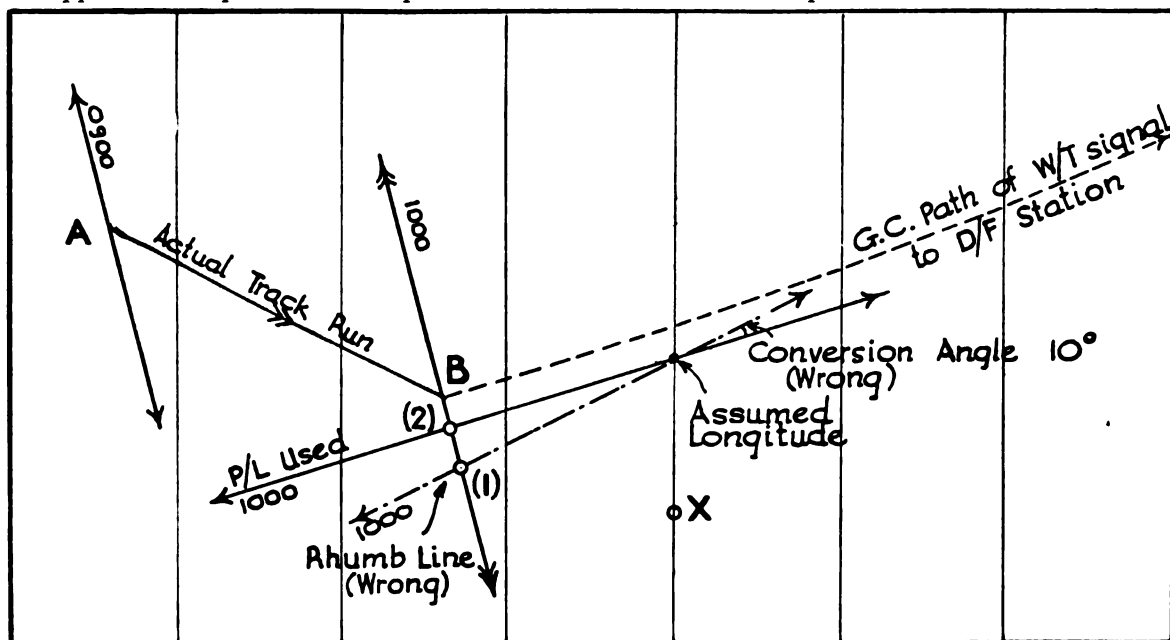


FIGURE 27. Refined Procedure for Plotting Great Circle Arcs.

Example :—

36. Figure 27 illustrates the case of an aircraft in the *Southern Hemisphere*, whose actual positions at 09.00 hours and 10.00 hours are shown as A and B on a Mercator's chart. A position line was obtained at 09.00 by transit, the plotting of which is considered to offer no difficulty. A second position line was obtained at 10.00 hours from a far-distant D/F station. The actual position, B, at 10.00 hours, is fixed by the intersection of the great circle arc representing the second position line, with the first position line transferred for the actual run.

Suppose that the assumed position of the aircraft at 10.00 hours was at X. This would cause the conversion angle to be slightly under-estimated at, say, 10° . Over the distance envisaged, an error of only $\frac{1}{2}^\circ$ would cause the rhumb line laid off from the D/F station to pass appreciably to one side of the actual position, B, as is shown. Thus, in Figure 27, Fix (1) is considerably in error. By adopting the refined procedure, Fix (2) is obtained, the merits of which are obvious.

37. Consideration has been given to the possible provision of tracings of Great Circle Bearings projected by *Astrograph* (see Chapter VII, paragraph 40) or some similar instrument, and applicable to origins situated in various bands of Latitudes for use on Mercator's Plotting Charts, series G.S.G.S.4080. The tracing applicable to a particular origin could then be thrown upon the Mercator's chart and aligned so that the meridian at the origin was coincident with the 000° — 180° bearing on the tracing.

The requisite great circle bearing, or that part of it required as a position line, could thus be drawn in with a pencil directly on the plotting chart. Such a device would greatly simplify the plotting of all D/F bearings, where the conversion angle is too large to be overlooked.

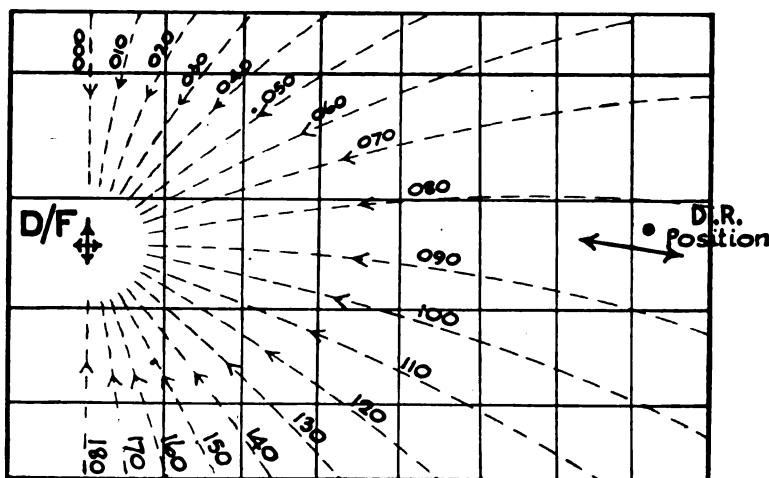


FIGURE 28. Great Circle Tracing for Mercator's Projection.

38. An example of such a Great Circle Bearing Tracing is shown diagrammatically in Figure 28, where a Position Line for a bearing of 085° T from a D/F station is shown drawn in the vicinity of the D.R. position.

An Arc of a Small Circle

39. All position lines obtained from ranges and from astronomical origins are arcs of small circles. For all practical purposes the latter are plotted as straight lines, and thus offer no special problem to the Navigator (see Chapter VII, paragraph 6); while the former are drawn simply by means of a pair of compasses centred on the origin and extended by the range, to scale.

An Arc of a Curve of Equal Bearing

40. Where the great circle bearing of an origin is measured at the meridian of an aircraft, as in the case of all compass, pelorus or loop bearings, the position line is an arc of the Curve of Equal Bearing.

This is due to the Convergency of meridians. (See Chapter III, paragraph 60.) It will be agreed, after inspection of Figure 29, which represents an exaggerated topographical map graticule, that the great circle bearings of an origin X from positions A, B, C, D, E, F, G and H are all 050° T. A Navigator observing such a bearing might be situated *anywhere* on the locus of such points. In fact, he must be

somewhere on a curve upon which all the great circle bearings of X will be equal to 050° T. He cannot be at a point on a great circle other than where the Curve of Equal Bearing cuts it. Compare the bearing of X from A with its bearing from I, an intermediate point on the great circle joining A to X. At I it can be seen that X bears 070° T.

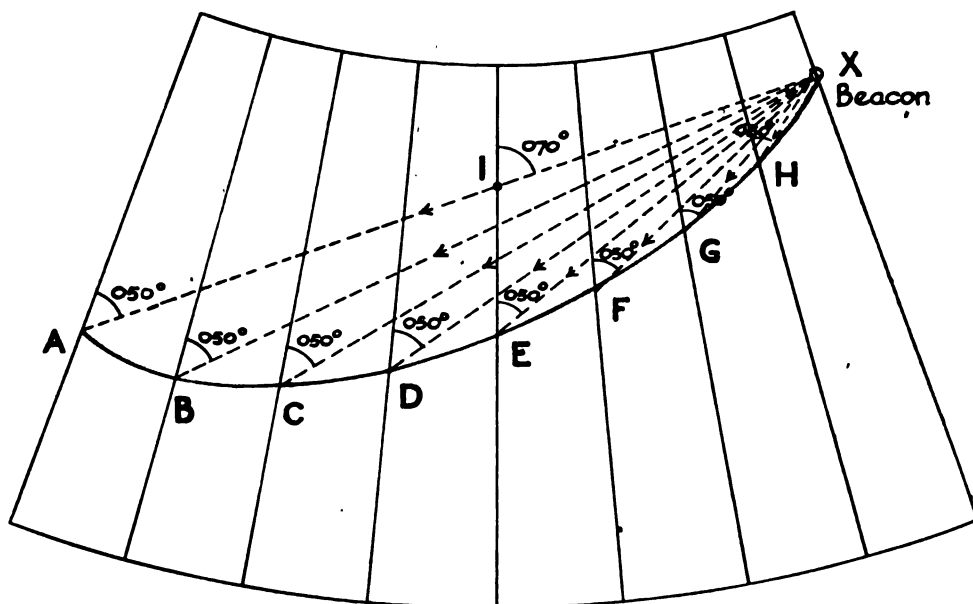


FIGURE 29. An Arc of the Curve of Equal Bearing of X of 050° T.

41. Figure 30 illustrates the approximate appearance of a Curve of Equal Bearing of 030° T of origin X in *Polar* regions, where the Convergency of meridians may be regarded as equal to the Change of Longitude between them. It will be seen that points A, B, C, D, X and P are concyclic, since the angles subtended by XP at A, B, C and D are all equal.

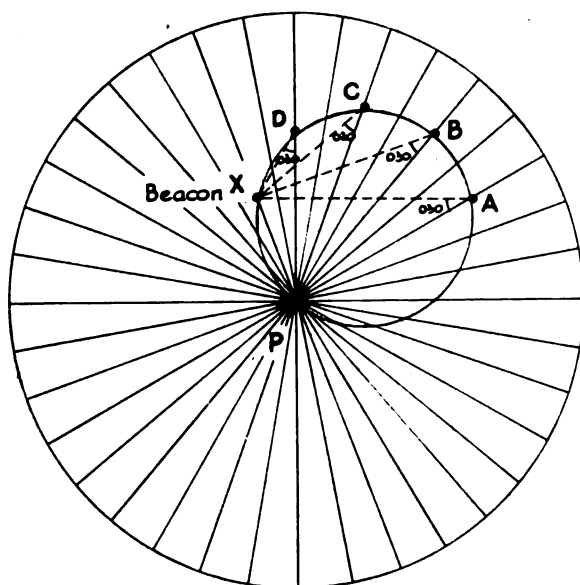


FIGURE 30.
A Curve of Equal Bearing of 030° T in Polar Regions.

As the Polar regions are left, the Convergency of meridians decreases. Consequently Figure 30 represents less and less the appearance at lower Latitudes of the Curve for the same bearing. Points upon the Curve may be calculated by the use of Napier's Circular Parts formula, with which only students of A.P. 1456 need be familiar.

42. The significance of the foregoing may best be judged from Figure 31, which represents a Mercator's graticule upon which a great circle bearing of 060° T is the basis of the Curve of Equal Bearing of an origin situated at Cambridge, England.

43. It should be noted that the angle between the great circle and the Curve of Equal Bearing is approximately bisected by the rhumb line between any point on the curve and the origin. It should be clear from Figure 31 that great circle, rhumb line and Curve of Equal Bearing may all be different lines. It may be observed, however, that a meridian functions as all three for bearings of 180° T or 360° T of any origin.

44. Over short distances, the distinction between rhumb lines, great circles and Curves of Equal Bearing can be neglected. Thus, in all bearings obtained visually from the aircraft, the position line may be plotted as a straight line, making an angle at the origin equal to the reverse of the observed True bearing. For the same reason it is possible to lay down hard and fast rules for plotting all loop bearings.

Plotting Loop Bearings

45. The method of obtaining True loop bearings is described fully in Chapter IX. How they may be used as position lines depends upon the properties of the map upon which they are plotted. There are only two cases, since Gnomonic charts cannot be used for plotting Curves of Equal Bearing.

Loop Bearings on Topographical Maps

46. Either :—

(i) (a) At the origin, draw a *false meridian* parallel to the meridian of the D.R. Position of the aircraft ; and

(b) from this line lay off at the origin the reverse of the True great circle bearing obtained by loop, as the position line.

Or :

(ii) (a) Calculate or measure the Convergency between the meridian of the aircraft and that of the origin, applying it to the reverse of the True great circle bearing obtained by loop (a rough sketch gives the best indication of whether to add or subtract) ;

(b) lay off this bearing from the origin as the position line.

Example :—

47. At 15.00 hours a Navigator in D.R. Position 50° N 04° E obtains a loop bearing of 327° T of a radio beacon, B, situated in 52° N 02° W. The first method of plotting this on a topographical map is illustrated in Figure 32.

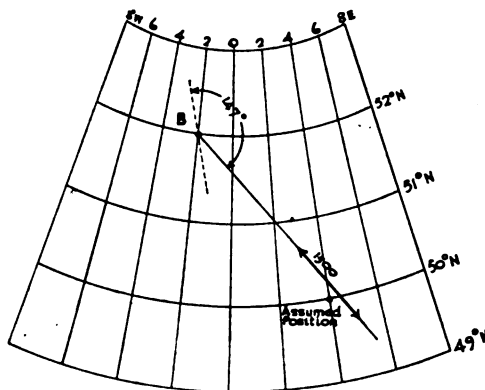
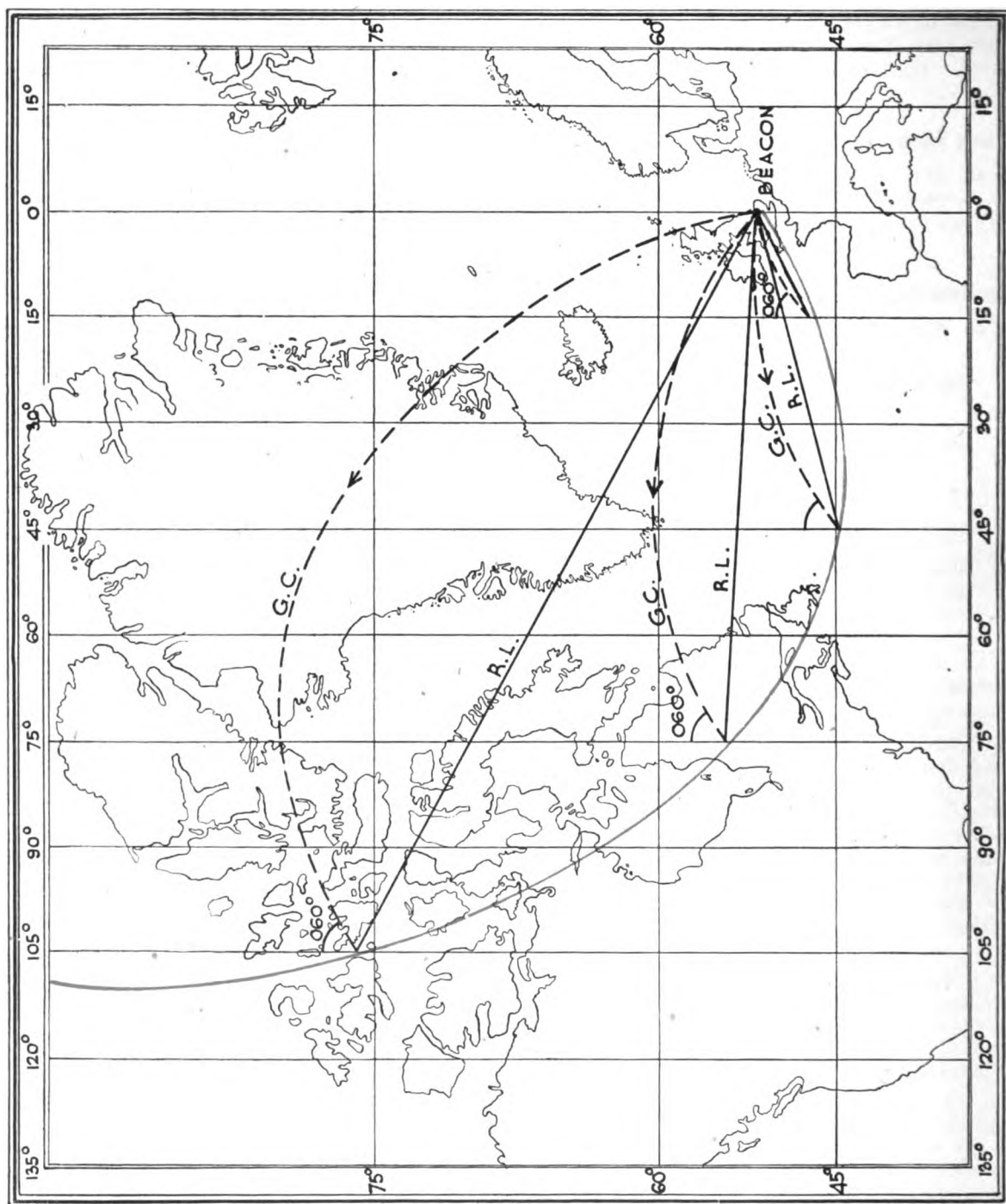


FIGURE 32. Plotting a Loop Bearing on a Topographical Map.

The bearing laid off from the false meridian at B is the reverse of the loop bearing, i.e. $(327^{\circ} \text{ T} \pm 180^{\circ}) = 147^{\circ} \text{ T}$.



Following the second method, the Convergency is calculated to be $(6^\circ \times \sin 51^\circ =) 5^\circ$, approximately.

Convergency is SUBTRACTED. (See sketch.)

The reverse of the loop bearing is 147° T as before.

Hence the bearing to lay off from the meridian of the beacon is $(147^\circ - 5^\circ) = 142^\circ$ T, as illustrated in Figure 33.

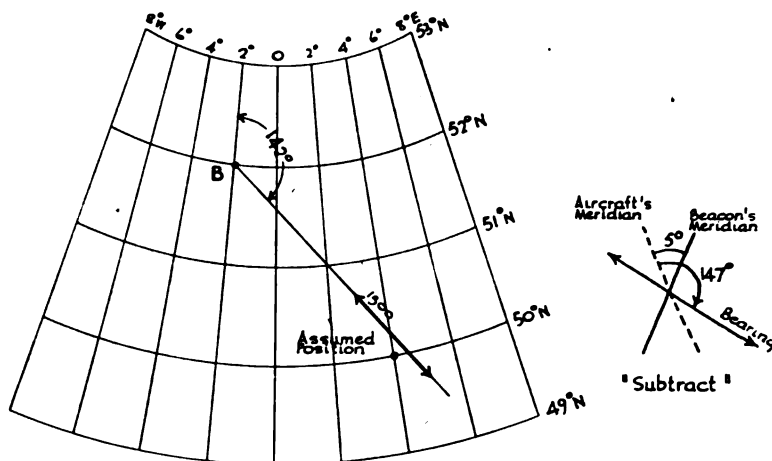


FIGURE 33. Plotting a Loop Bearing on a Topographical Map.

Loop Bearings on Mercator's Plotting Charts

48. (i) Calculate conversion angle between the position of the origin and the D.R. Position of the aircraft.
- (ii) Apply this to the True great circle bearing obtained by loop, to get the rhumb line bearing. (Draw a rough sketch.)
- (iii) Lay off from the origin the reverse of the rhumb line bearing as the position line in the vicinity of the D.R. Position.

Example .—

49. Plot the position line obtained by a Navigator at 16.00 hours, in D.R. Position $52^\circ 15' \text{ N } 10^\circ 40' \text{ E}$, when the loop bearing of a Radio Beacon, B, in position $52^\circ 00' \text{ N } 02^\circ 20' \text{ W}$, was 270° T.

The C.A. is $(6.5 \times \sin 52^\circ) = 5^\circ$. This must be SUBTRACTED (see sketch) from the True great circle bearing obtained by loop.

The rhumb line bearing is therefore $(270^\circ - 5^\circ) = 265^\circ$ T.

The reverse of this, i.e. $(265^\circ \pm 180^\circ) = 085^\circ$ T, is laid off as the position line from the Beacon. (See Figure 34.)

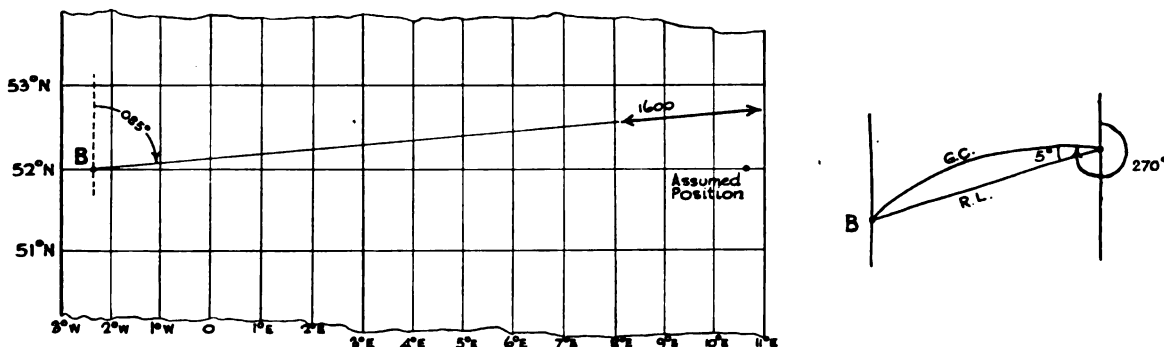


FIGURE 34. Plotting a Loop Bearing on Mercator's Projection.

Further Refinements for Plotting Loop Bearings

50. It will be remarked that in both the examples cited above, position lines from loop bearings have been considered as arcs of great circles or as rhumb lines, when it is known that they should be drawn as arcs of *Curves of Equal Bearing*. This procedure is adopted in practice because the increased accuracy resulting from their proper plotting is at present outweighed by the inaccuracies inherent in the bearings themselves. As radio aids to Navigation increase in range and accuracy it may become necessary to adopt a further step in plotting position lines obtained by means of loops in aircraft, as follows :—

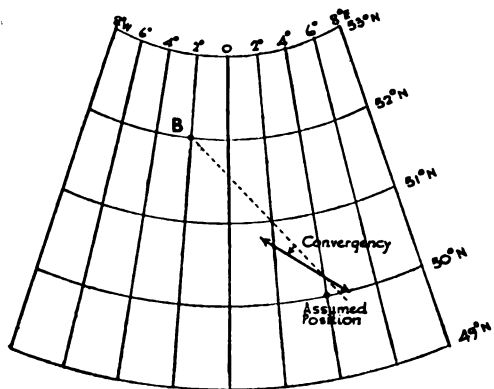


FIGURE 35. Refined Procedure for a Topographical Map.

(i) Using Topographical Maps

Where the great circle bearing, drawn from the origin, cuts the meridian of the D.R. Position, draw a line to represent an arc of the Curve of Equal Bearing in that vicinity. This line is inclined approximately at the angle of Convergency to the great circle already drawn, and lies towards the origin on the same side of the great circle as the Equator.

In Figure 35, the refinement is applied to the example already given in Figure 33.

(ii) Using Mercator's Charts

Where the rhumb line bearing, drawn from the origin, cuts the meridian of the D.R. Position, draw a line to represent an arc of the Curve of Equal Bearing in the vicinity of the aircraft. This line is inclined approximately at the Conversion Angle to the rhumb line already drawn, and lies towards the origin on the same side of the rhumb line as the Equator.

In Figure 36 the refinement is applied to the example already given in Figure 34.

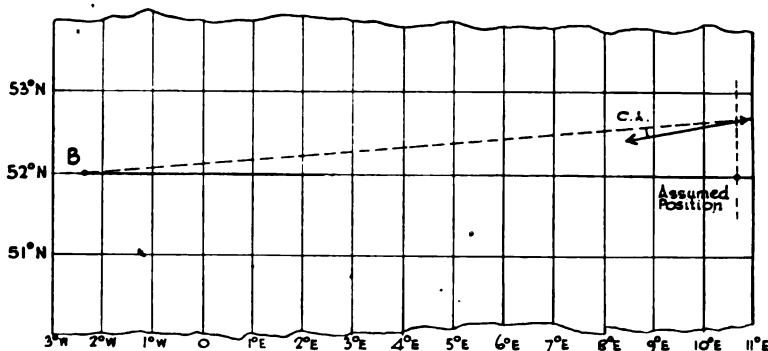


FIGURE 36. Refined Procedure for Mercator's Projection.

Curve of Equal Bearing Tracings

51. Consideration has been given to the provision of tracings of Curves of Equal Bearings that could be projected by *Astrograph* (see Chapter VII, paragraph 40) or some similar instrument upon Mercator's Plotting Charts, series G.S.G.S. 4080. By orienting the origin of the Curves at the location of the beacon on the map, a part of the appropriate curve in the vicinity of the D.R. Position could be quickly drawn in pencil on the map. This would obviate the tedious procedure outlined above for plotting position lines from loop bearings when the Convergency is a sensible quantity.

Plotting a Position Line from Any Origin Situated Off the Map or Chart in Use

52. When the Navigator is on a flight, during which long-range position lines are likely to be available from D/F sources, the occasion may arise when he will wish to use a position line obtained from an origin that is situated off the actual map sheet or chart he is using at that time. The simplest method

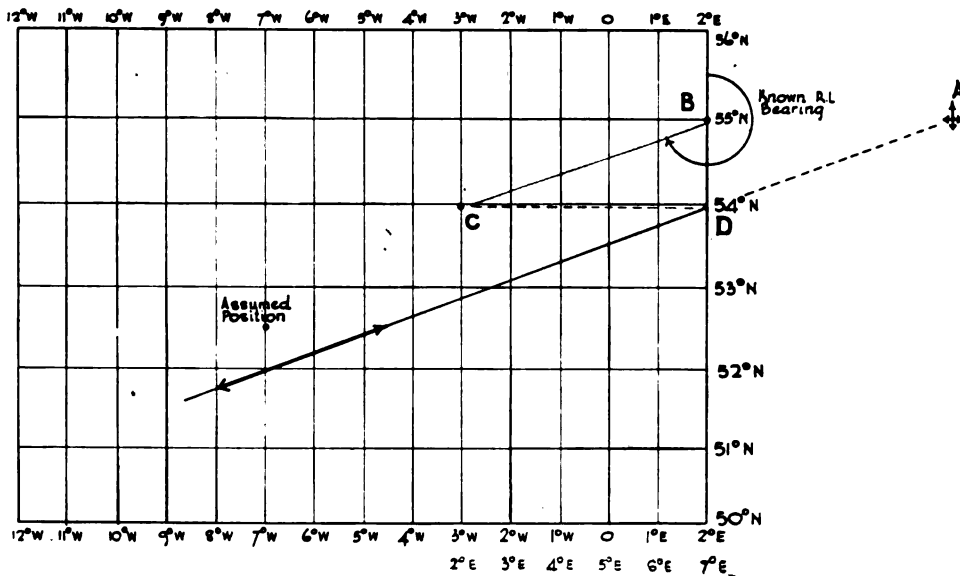
of dealing with such position lines is to have a small-scale map or chart covering the whole area of the flight upon which such a position line may be directly plotted. Either the position line may be transposed on to the larger-scale sheet in use from the small-scale sheet ; or the purpose of the position line (e.g., plotting a fix) may be fulfilled on the small-scale map and the results transferred to the larger-scale sheet. The One/Million Plotting Charts (G.S.G.S. 4080) have been devised with this possibility, among others, in view.

When no small-scale sheet is available, other means of plotting such a position line are required, as follows :—

Graphical Method, Using a Mercator's Chart

53. This consists of simply re-numbering the graticule of the sheet in order to accommodate the origin, from which the rhumb line bearing is laid off.

The student will realise from the description of Mercator's projection in Chapter III that the re-numbering of the graticule must be limited to the re-numbering of *meridians*, since the spacing of the parallels of latitude expands North or South of the Equator. It follows that this method can only cater for those cases where the Latitude of the origin falls within the Latitude-band of the chart in use.



Method of Calculation, Using a Mercator's Chart

55. Owing to the limitations of the graphical method it may be desirable or necessary to plot the position line from a subsidiary point, such as D in Figure 38, located by calculation. Two possibilities will be considered, according to whether the origin lies most nearly within the same limits of Latitude, or Longitude, as the Mercator's chart in use.

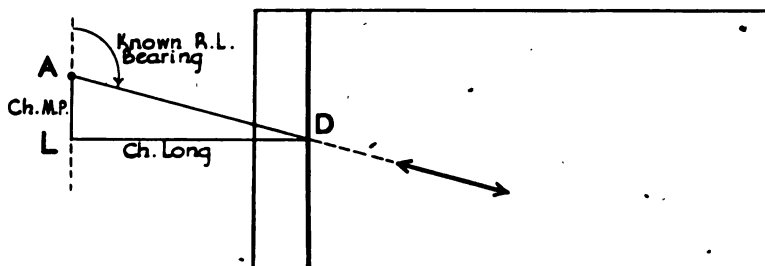


FIGURE 38. Origin Off the Chart in Use (East and West Case).

(i) The East and West Case

Where the origin is East or West of the chart in use, the following procedure is adopted.

Select a meridian on the chart edge, nearest the origin. In Figure 38, A is the origin, and the selected meridian is shown in Red.

Calculate the *Latitude* of D, the point at which the rhumb line bearing will cut the selected meridian as follows :—

Let the parallel of latitude through D be represented by DL.

Then DL, in length, equals the chart length of the number of minutes of Longitude between the selected meridian and the meridian of the origin.

Since A's position is known, and angle LAD may be deduced from the known rhumb line bearing, and since triangle ALD is right-angled at L, AL may be calculated (in Ch. Mer. Parts). Hence the Latitude of D is calculated by applying this Change of Mer. Parts to the Mer. Parts for A's Latitude. The rhumb line bearing is then laid off from D, as though it were a subsidiary origin.

Example :—

Plot a rhumb line bearing of 104° T from origin A, which is 20° west of the nearest meridian on a Plotting Chart. The Latitude of A is $52^\circ 10' \text{ N}$. At what Latitude on the nearest meridian on the chart will the bearing be laid off? (See Figure 38.)

LD, the Ch. Long. from A to the nearest meridian = 20° W	
= 1200' W	
$104^\circ \text{ T} = 180^\circ \text{ T} - 76^\circ$	
$\therefore \text{Angle LAD} = \text{S } 76^\circ \text{ E}$	
Now $\cot \text{LAD} = \frac{\text{LA}}{\text{LD}}$	
$\therefore \text{LA} = \text{LD} \times \cot \text{LAD}$	
whence LA, the Ch. M.P. from A to D = 299.2 S	
From Meridional Parts Tables, Lat. $52^\circ 10' \text{ N}$ = 3662.97 N	
But the Ch. M.P. is 299.2 S	
$\therefore$ The Mer. Parts of L = 3363.77 N	
Whence (from the same Tables) the Lat. of L = 49° N	
This is the same as the Latitude of point D.	

$\log 1200'$	= 3.07918
$\log \cot 76^\circ$	= 1.39677
$\therefore \log \text{LA}$	= 2.47595

Therefore the position of D can be plotted on the chart in use, and the rhumb line bearing laid off correctly from D instead of from A.

(ii) *The North and South Case*

Where the origin lies outside the North and South boundaries of the chart, the position line can be plotted only after calculation, in the absence of a small-scale sheet.

Select a parallel of Latitude and proceed to solve the right-angled triangle formed by the meridian of the origin and the selected parallel, the apex of which is the origin.

This entails the reverse procedure to that described above, since the known side consists of the Ch. M.P. between the origin and the selected parallel. (See Figure 39.)

Example :—

A is an origin in position $52^{\circ} 40' \text{ N } 01^{\circ} 20' \text{ E}$, from which it is desired to lay off a rhumb line bearing of 220° T . The most northerly parallel on the Plotting Chart in use is 48° N . At what Longitude on the latter parallel is the point D, from which the rhumb line bearing may be laid off? (See Figure 39.)

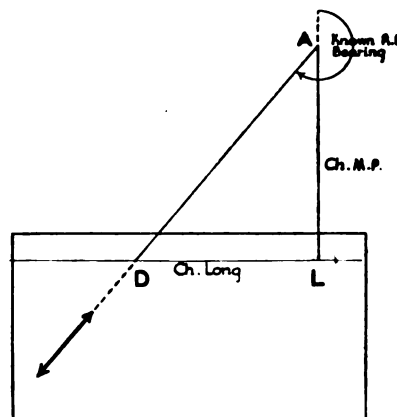


FIGURE 39. Origin Off the Map in Use (North and South Case).

From Mer. Part Tables, Lat. $52^{\circ} 40' \text{ N} = 3712.03 \text{ N}$
and Lat. $48^{\circ} 00' \text{ N} = 3274.13 \text{ N}$

$\therefore$ Ch. Mer. Parts from A to L $= 437.90 \text{ S}$
 $220^{\circ} = 180^{\circ} \text{ T} + 40^{\circ}$

$\therefore$ Angle LAD $= \text{S } 40^{\circ} \text{ W}$

Now DL, the Ch. Long. from A to D $= \text{AL} \times \tan \text{angle LAD}$

$= 367' \text{ W}$
 $= 6^{\circ} 07' \text{ W}$

But Long. of A $= 01^{\circ} 20' \text{ E}$

$\therefore$ Long. of D $= 04^{\circ} 47' \text{ W}$

$\log 437.9 = 2.64138$

$\log \tan 40^{\circ} = 1.92381$

$\therefore \log \text{Ch. long.} = 2.56519$

Note.—The choice of a parallel rather than of a meridian avoids the danger of finding that the intersection on the selected line is still off the chart.

(iii) *The Intermediate Case*

When the origin is off one corner of the chart, the position line can only be plotted after making similar calculations to those described above.

Graphical Method, Using a Topographical Map

56. If a small-scale map is not available, the only practical method of plotting a great circle position line from an origin, situated off the sheet in use, is by re-numbering the graticule of the sheet to accommodate the origin. This introduces errors which increase with the distance which the origin is from the sheet. The method of calculation is too complicated to be of any practical value. There are again three possible cases which can be solved graphically, as follows :—

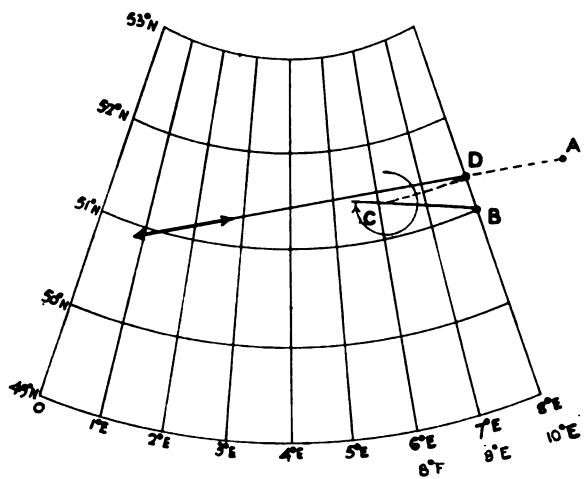


FIGURE 40. Re-numbering Meridians.

On the real 8° E meridian, mark off D at the same latitude as C. From D lay off the bearing that was measured at C, namely, 288° T.

This now serves as the plotted position line and satisfies the conditions for most practical purposes.

(ii) *The North and South Case*

Where the origin is North or South of the latitude boundaries of the map-sheet in use, the procedure is somewhat similar, except that the parallels of latitude, instead of the meridians, are re-numbered, prior to plotting the "false" origin.

The re-numbering of the parallels introduces appreciable errors if extensive re-numbering is necessary. The practice can therefore be regarded as useful in **only very limited conditions**, and the position line must be accepted with reserve.

Example :—

It is desired to lay off a great circle bearing of 140° T from an origin A, situated in 55° N 04° W, on to a map, the most northerly parallel of which is 54° N.

Re-number the parallels 53° N and 54° N as 54° N and 55° N respectively (see Figure 41).

Plot B as the "false" origin, using the re-numbered graticule.

Lay off the bearing 140° T from B, cutting the re-numbered parallel of 54° N at C.

Through C draw a line parallel to the meridian through B, cutting the real 54° N parallel at D.

From D draw a line parallel to BC. This is the great circle bearing that satisfies the conditions for most practical purposes.

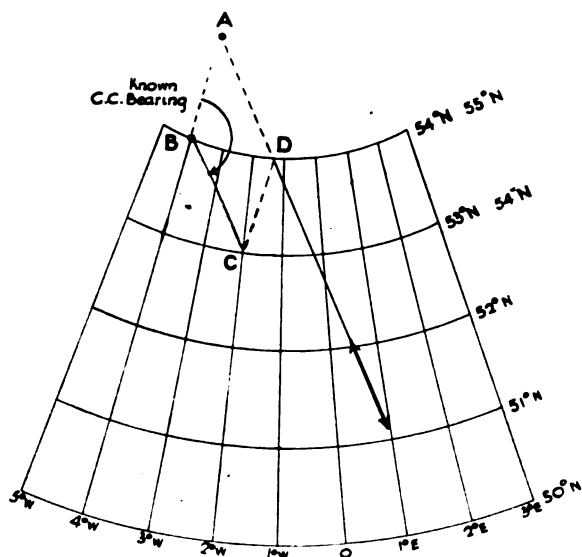


FIGURE 41. Re-numbering Parallels of Latitude.

(iii) *The Intermediate Case*

When the origin lies off one corner of the map, both meridians and parallels have to be re-numbered as described above. For this reason it is not possible to plot the position line with much accuracy, especially when the parallels have to be re-numbered.

CHAPTER VII

ASTRONOMICAL NAVIGATION

"Why," said the Dodo, "the best way to explain it is to do it."

—ALICE IN WONDERLAND.

Introduction

1. The beginner must not be misled by the long-sounding title of this Chapter into thinking that entirely different principles of Navigation are involved. In actual fact, Astronomical Navigation only provides a means of obtaining position lines. The uses of position lines have already been described in Chapter VI. Astronomical Navigation is so valuable because the Air Navigator can obtain an accurate position line without help from the ground. He can, therefore, be indifferent to the length of time he has been out of touch with the ground. Moreover, as modern aircraft can operate at well over 15,000 ft., there are only few occasions when clear skies are really inaccessible. The purpose of this Chapter is to give the practical Air Navigator an outline of why and how a position line can be obtained by observing the *altitude* of a Heavenly Body; that is to say, by measuring the angle at the Navigator's eye between the horizontal and the Body in question.

The Sub-stellar Point

2. The Earth is one of several rotating planets moving round the Sun, itself one of the smaller members of a galaxy of stars. The Earth possesses a satellite called the Moon. The stars are an immense distance away, so far indeed that no change is noticeable in their relative positions when seen from points nearly 200 million miles apart, that is, from either end of a diameter of the Earth's yearly path round the Sun. Nevertheless, the Earth being spherical, at any instant of time there is a point upon its surface lying directly beneath each Heavenly Body, whether Sun, Moon, Planet or Star. For the sake of convenience, this will be referred to as the *Sub-stellar Point*, though strictly the term applies only to Stars. It is where the line joining the Body to the centre of the Earth cuts the surface.

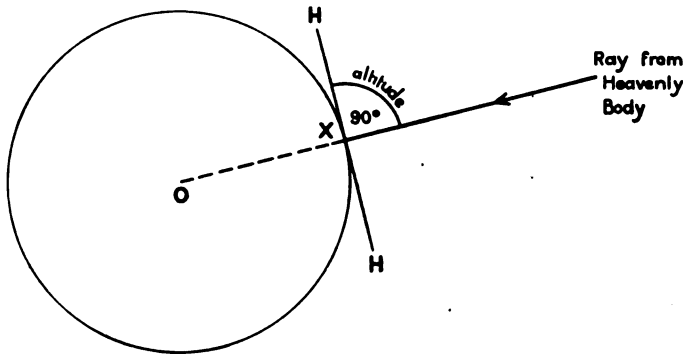


FIGURE 1. The Altitude at a Sub-stellar Point.

3. To an observer who happens at that instant to be situated on the sub-stellar point, the Body will be directly overhead. If he were to measure its altitude at that moment, he would find it was exactly 90° . This fact is illustrated in Figure 1 where :—

X is a sub-stellar point.

O is the centre of the Earth.

HH is the horizontal at X (therefore, *tangent* at X).

It can be seen that the altitude of the Body measured at X is 90° .

4. Even to the casual observer of the skies it is obvious that the sub-stellar point is continually moving over the surface of the Earth as the latter rotates. The sub-stellar point of a Star moves round the Earth on a Parallel of Latitude. In the course of centuries the movement of the Moon and Planets and the apparent movement of the Sun and Stars have been carefully studied, so that in practice the

sub-stellar point can be accurately predicted for any Heavenly Body at any desired instant of time. Time is, therefore, the first consideration when making astronomical observations. The Time system universally employed in astronomical observations and predictions is Greenwich Mean Time (see Chapter IV).

The Position Circle

5. Rays of light from a Heavenly Body are parallel to one another at the Earth owing to the vast distance they have come from the Body (the comparative nearness of the Moon introduces a special problem dealt with in paragraph 34). To an observer not situated on the sub-stellar point, the altitude of the Body will measure less than 90° . Exactly how much less depends upon the distance of the observer from the sub-stellar point. It follows that observers who at the same instant of time all find the same altitude of the Body must themselves be at the same distance from the sub-stellar point. This important conclusion can be summarised by saying that *at any given instant, places on the Earth, where the observed altitude of a Heavenly Body is the same all lie on the circumference of a circle whose centre is the sub-stellar point*. This is called a "Position Circle".

The radius of the position circle naturally determines the altitude observed from any place upon it. Look at Figure 2.

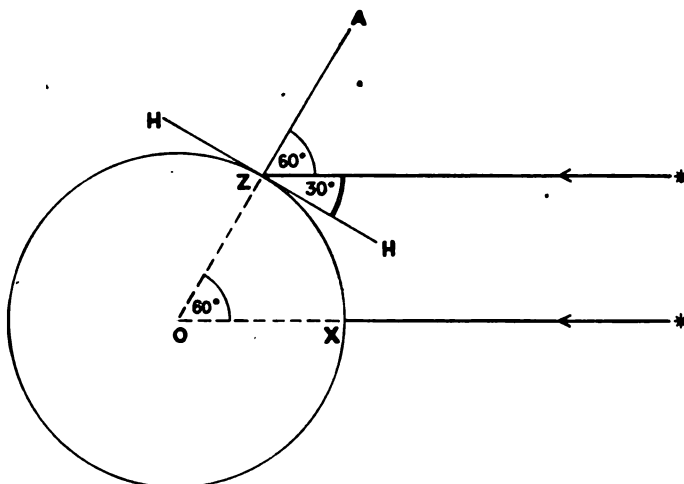


FIGURE 2. The Connection between Altitude and the Radius of the Position Circle.

X is the sub-stellar point ;
Z is a place distant 60° (or 3,600') of arc from X ;
O is the centre of the Earth.

Hence angle ZOX = 60° .

AZO is the true vertical at Z ;

$\star O$, $\star Z$, are parallel rays of light ;

$\therefore$ Angle AZ $\star$ = corresponding angle ZOX ;
= 60° .

HZH is the true horizontal at Z.

$\therefore$ Angle AZH = 90° ;

But angle AZ $\star$ = 60° ;

$\therefore$ Angle HZ $\star$ = 30° .

This is the angle of altitude of $\star$ at Z.

Thus the observed altitude is the complement* of the distance in arc from the sub-stellar point to the observer.

Conversely, the distance in arc from the observer to the sub-stellar point is the complement of the observed altitude.

* The complement of an angle is the difference between it and 90° .

This means to say that if, for example, an altitude of 30° is observed, the Navigator must be somewhere on the circumference of a circle whose centre is the sub-stellar point and whose radius is ($90^\circ - 30^\circ = 60^\circ$ of arc, namely, 3,600 n.m. (see Figure 2).

By noting the exact G.M.T. which, as has been stated, enables the sub-stellar point to be located, and by taking the altitude of a Body, the Navigator determines the centre and radius of a circle, part of whose circumference he will wish to use as a position line. The whole or part of the position circle, as required, could accordingly be drawn directly upon a globe.

Plotting Part of a Position Circle

6. For reasons that need not be stated here, altitudes of much less than 20° and more than 80° are rarely used by Navigators. Hence, as a rule the radius of a position circle is between 600 and 4,200 n.m. in length. Since all Air Navigation is carried out on maps or charts covering relatively small areas, it is obviously impossible to plot the sub-stellar point upon the *local* map in use. Another method has been devised on the following principle :—

Since at any given instant position circles corresponding to various altitudes of the same Body are *concentric*, their distance apart must be equal to the difference between their respective radii, which is the same as the difference in arc between the various altitudes concerned.

The method is as follows :—

(i) The most convenient* position near the Navigator's D.R. position is selected and called the *Assumed Position*.

(ii) The Navigator extracts from tables the *predicted* altitude and bearing of the Body from the Assumed Position, for the instant of time in question.

(iii) The predicted bearing (or *Azimuth*, as it is called) of the sub-stellar point is laid off through the Assumed Position on the map.

If this line were sufficiently extended it would, of course, pass through the sub-stellar point the common centre of all position circles at that time.

(iv) The altitude given by the tables is compared with the altitude actually observed by the Navigator. Now any difference in arc between altitudes is equal to the difference in length between the radii of the corresponding position circles. The radius of the position circle on which the assumed position lies is terminated by the Assumed Position itself. Any radius less than this will terminate on that side of the Assumed Position *towards the sub-stellar point*, by an amount equal to the difference in arc between the two altitudes, and vice versa. This difference between the observed and tabulated altitudes (and therefore between the radii) is called the *Intercept*, and is named "*Towards*" or "*Away*" if the observed position circle is nearer to or further from the sub-stellar point than the Assumed Position circle.

The purpose of the Intercept is to indicate a point on the line of Azimuth ((iii) above) through which the observed, and therefore the actual, position circle must pass (see paragraph 7).

(v) Altitudes greater than 80° are rarely used in practice. This implies that the radius of the observed position circle is usually at least 10° of arc in length, i.e. ($10^\circ \times 60' = 600$ n.m.

Now the curvature of the circumference of such a circle is extremely slight. Consequently, a short arc of the circumference may without sensible error be represented by a tangent.

Thus through the point determined on the line of Azimuth by the Intercept, a short line is drawn at right-angles to the line of Azimuth. This line is the *astro position line*, being part of the observed position circle.

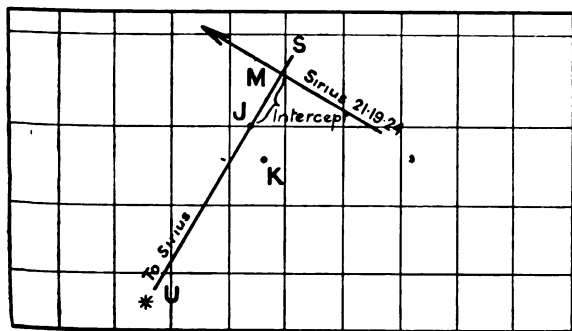


FIGURE 3. Plotting an Astro Position Line.

* Choice of the most convenient position is explained in paragraph 13.

Example :—

7. An Air Navigator wishes to plot an astro position line. At 21.19.24 G.M.T., on April 1st, 1941, G.D., the star SIRIUS is observed to have a true altitude of $41^{\circ} 19'$. The D.R. position is at K (see Figure 3). For convenience of calculation, the Navigator takes J as his Assumed Position.

From the tables he finds that at 21.19.24 G.M.T., on April 1st, 1941, G.D., the altitude of SIRIUS from J would be $42^{\circ} 05'$, and its Azimuth $209^{\circ} T$.

As in Figure 3, a line SU is drawn through J in the direction of $209^{\circ} T$.

Since the observed altitude is *less* than the tabulated altitude by $46'$, the Intercept must be " $46'$ away".

JM, a distance of 46 n.m., is measured from J, *away* from the direction of the star. Through M a line is drawn at right-angles to SU. This is the astro position line and is designated accordingly.

Astronomical Tables

8. So far it has been glibly stated that the altitude and azimuth of a Heavenly Body at an assumed position for a particular instant of time can be "*extracted from Tables.*" The tables fall into two classes :—

The Air Almanac (A.P. 1602)

9. This gives day-to-day information of each Heavenly Body used in Air Navigation, and is published three times a year. It primarily contains all the astronomical predictions relevant to the location of the sub-stellar point. Sub-stellar points, like other positions on the Earth, may be defined by their Latitude and Longitude, only the terms used are different.

10. The Latitude of a sub-stellar point is the equivalent of the *Declination* of the Body. Both are measured exactly alike, and are named either North or South.

11. The Longitude is obtained in terms of ch. long. from some meridian, not necessarily that of Greenwich but, indeed, more frequently that of the Navigator's position. It is always measured westwards from 0° to 360° and is called the *Hour Angle* of the Body, the name being derived from the close relationship existing between time and arc (see Chapter IV, paragraph 14).

When an hour angle is measured from the Greenwich meridian it is called a *Greenwich Hour Angle* (G.H.A.). (See Figure 4.)

When a hour angle is measured from the Navigator's meridian, it is called a *Local Hour Angle* (L.H.A.) or simply an *Hour Angle* (H.A.) for short. (See Figure 4.)

The difference between G.H.A. and L.H.A. is none other than the change of Longitude between Greenwich and the Navigator ; that is to say, it is the Navigator's Longitude. In other words :—

$$\text{L.H.A.} = \text{G.H.A.} \begin{matrix} +E \\ -W \end{matrix} \Bigg\} \text{Longitude.}$$

How to obtain Hour Angles

12. (i) *Sun, Moon, Planets.*—The G.H.A. is tabulated separately for any moment of Time for the Sun, Moon and Planets. To obtain the (Local) Hour Angle, the Navigator's Longitude must accordingly be applied. Thus :—

$$\begin{aligned} (\text{L.}) \text{ H.A. Sun} &= \text{G.H.A. Sun} \begin{matrix} +E \\ -W \end{matrix} \Bigg\} \text{Longitude,} \\ \text{and } (\text{L.}) \text{ H.A. Moon} &= \text{G.H.A. Moon} \begin{matrix} +E \\ -W \end{matrix} \Bigg\} \text{Longitude,} \\ \text{and } (\text{L.}) \text{ H.A. Planet} &= \text{G.H.A. Planet} \begin{matrix} +E \\ -W \end{matrix} \Bigg\} \text{Longitude.} \end{aligned}$$

(ii) *Stars.*—The G.H.A. is also tabulated for an imaginary position in the heavens called the *First Point of Aries* (γ) which always has a sub-stellar point on the Equator.

$$\text{Hence } (\text{L.}) \text{ H.A. } \gamma = \text{G.H.A. } \gamma \begin{matrix} +E \\ -W \end{matrix} \Bigg\} \text{Longitude.}$$

Such an imaginary position is useful for measuring the hour angles of Stars, since their positions change only very slowly with reference to the First Point of Aries. Hour angles of stars measured from Aries are called *Sidereal Hour Angles* (S.H.A.). Thus if the sub-stellar point of a star is 1° E of that of Aries, its S.H.A. will be 359° and will remain so until a correction eventually becomes necessary.

As the G.H.A. τ is tabulated for any moment of Time, and the S.H.A. of any useful star is also tabulated, the sum of the two will give the Greenwich Hour Angle of the star. Thus :—

$$\text{G.H.A. } \star = \text{G.H.A. } \tau + \text{S.H.A. } \star$$

Whence the (Local) Hour Angle of the star can be derived :—

$$\text{H.A. } \star = \text{G.H.A. } \tau + \text{S.H.A. } \star \begin{matrix} + \text{E} \\ - \text{W} \end{matrix} \text{ } \left. \vphantom{\begin{matrix} + \text{E} \\ - \text{W} \end{matrix}} \right\} \text{Longitude.}$$

These cryptic sums can be followed more clearly from Figure 4.

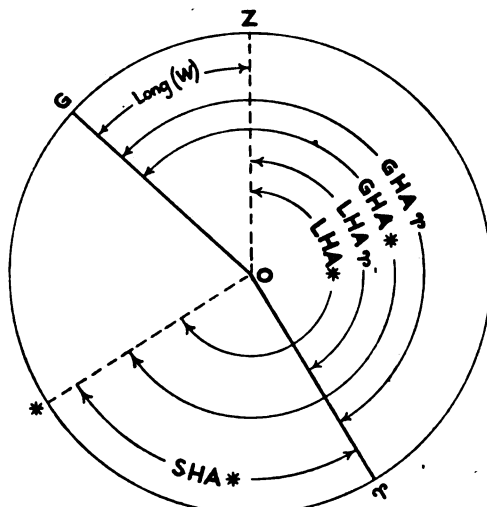


FIGURE 4.
Hour Angles seen from Above the North Pole.

Choice of an Assumed Position

13. In practice the (Local) Hour Angle of a Body is usually required for an *Assumed Position*. To simplify subsequent calculations a Longitude is always chosen to make the (Local) Hour Angle come to a *whole number of degrees*. It often happens that (Local) Hour Angle either exceeds 360° or is less than 0° . In such cases $\pm 360^\circ$ is applied.

Example :—

14. Assume a longitude approximately 8° E, and find the Hour Angle for an observation of the star ARCTURUS (No. 7) :—

S.H.A. $\star$	146° 46' (from <i>Air Almanac</i>).
G.H.A. τ	241° 27' (" " ")—for a particular moment.
$\therefore$ G.H.A. $\star$	388° 13'
Apply —	360° 00'
$\therefore$ G.H.A. $\star$	28° 13'
Assumed Longitude E +	7° 47' " <i>Greenwich Least</i> "
$\therefore$ H.A. $\star$	36° 00'

Example :—

15. Assume a Longitude approximately 27° W, and find the Hour Angle for a certain observation of the Sun :—

G.H.A. Sun	4° 35' (from <i>Air Almanac</i>)—for a particular moment.
Assumed Longitude W	—26° 35' " <i>Greenwich Best</i> "
$\therefore$ H.A. Sun	— " " 22° 00'
Apply +	360° 00'
$\therefore$ H.A. Sun	338° 00'

Astronomical Navigation Tables (A.P. 1618)

16. These give the solution of spherical triangles (*see* Chapter II, paragraph 7) of which two sides and the included angle are known. They are published in thirteen volumes, each volume catering for a particular band of Latitude extending over 5° , both North and South of the Equator.

Those who wish to know exactly which triangle is solved by the Astronomical Navigation Tables should look at Figure 5.

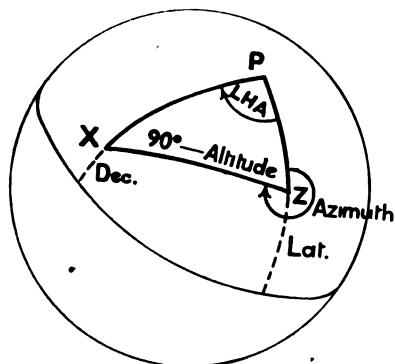


FIGURE 5. The Spherical Triangle solved by *A.N. Tables*.

The remaining side ZX and the angle PZX are what the Navigator requires; these are tabulated as the Altitude (complement of ZX) and Azimuth respectively, and are extracted simply by inspection.

Note.—The Declination of a star changes very slowly, hence each star is tabulated separately, and hence only two arguments, (ii) and (iii), appear to be used, the star's name and number being recorded as the third argument instead of Declination. The slow change of Declination is covered by minor corrections recorded as "i" in the *A.N. Tables*.

To help the Air Navigator to follow the correct procedure when using the *Air Almanac* and *A.N. Tables*, special Proformæ (F. 1519) are available. Their use is illustrated later in this Chapter.

Pole Star Observations and Q Correction

17. If there were a star whose sub-stellar point was at the Earth's Pole, it would provide a quick way of obtaining the Latitude of any place from which the star could be observed.

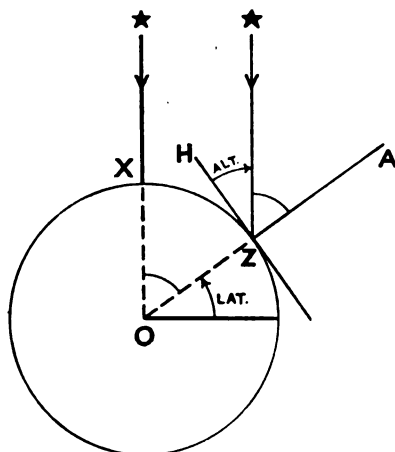


FIGURE 6. Pole Star Observations.

Z is the Navigator's Assumed Position.
P is the nearer Pole.
X is the sub-stellar point.
PZ is part of a meridian and measures, in arc, the complement of the Assumed Latitude, which, of course, is known.
PX is part of a meridian and measures in arc the complement of the Declination, which is given in the *Air Almanac*.
Angle ZPX is the (Local) Hour Angle of the Body, the derivation of which as a whole number of degrees has been explained in paragraphs 13 to 15.
Triangle PZX can be solved, the arguments with which the *A.N. Tables* are entered being:—

- (i) Declination (the complement of PX).
- (ii) Assumed Latitude (the complement of PZ).
- (iii) H.A. (the included angle ZPX).

Figure 6 illustrates rays of light from such a star. X is the sub-stellar point which, for the sake of argument, is taken to be the North Pole.

A Navigator at Z observes the Altitude of the star to be angle HZ★:—

O is the centre of the Earth;
OZA is the true vertical at Z;
★O, ★Z, are parallel rays of light;
∴ Angle ★OZ = corresponding angle ★ZA.
But ★ZO is the complement of the Latitude of Z
and ★ZA is the complement of the Altitude of ★;
∴ The Latitude of Z = the Altitude of the star.

In practice there is no such star over the South Pole; but *Polaris* is very nearly over the North Pole. A small correction called *Q* is given in the *Air Almanac* which, applied to *Polaris* Altitudes, gives the true Latitude. *Q* is tabulated against L.H.A. γ , the derivation of which was described in paragraph 12 (ii) above.

Star Identification

18. Apart from the Sun and Moon, and possibly a Planet or two (since these do not twinkle), the beginner may think it is a difficult matter to tell one Heavenly Body from another.

In actual fact, only the comparatively bright stars are useful in Air Navigation and these are all members of or close to the plainly recognisable *constellations* or groups of stars that go by various classic names, such as Orion, the Great Bear (or "Plough"), Pegasus, Cassiopeia, the "Sickle" and so on. Stars may be recognised most easily not as members of constellations, which often have poorly-defined shapes, but as forming super-constellations. Thus, for example, POLARIS can be found by producing the line joining the "Pointers", which form the front of the "Plough". In this way all the major stars may be memorised without effort.

For the *A.N. Tables*, data have been recorded for the 22 most suitable stars, and this number has been found by experience to be quite adequate. Of these stars only a few will be visible at any one time. Compared with knowing the 100 or so important capes, bays, and rivers of a country like the British Isles, the ability to identify any particular star of the few most suitable for Air Navigation on any one night would seem to be child's play.

All the stars have names, and for ease of reference they are also numbered. Any good star globe, or star atlas can be consulted when in doubt. The Navigator is provided with a *Planisphere* (see A.P. 1275B) which, after adjustment for L.H.A. τ , gives a life-like picture of the sky. Stars may also be identified by means of the *Astrograph* (see paragraph 40) and by the *Astro Compass* (see Chapter VIII). The R.A.F. Star Charts are reproduced at Appendix III.

Measurement of Altitudes

19. Altitudes of Heavenly Bodies are measured by optical instruments called *sextants*. While all give the angle at the Navigator's eye between the observed Body and the true horizontal, sextants fall into two types, according to the principle of operation. They are fully described in A.P. 1275B.

(i) *Marine Sextants*.—These instruments measure altitudes against the sea horizon. They give extremely accurate results, but are only useful when the sea horizon can be seen. This eliminates their use at night and when the sky is obscured over the sea, or when flying inland.

(ii) *Bubble Sextants*.—These instruments measure altitudes against the artificial horizon provided by a bubble trapped in liquid. Designs are varied, but the principle of operation in all types consists of viewing the Body through the exact centre of the bubble when the sextant is held level. The bubble is artificially illuminated at night, so may be used at all times. The Service pattern bubble sextant is provided with a means of suspension from the Astro-dome, which relieves the Navigator of strain and improves results considerably.

20. Some little manual skill is necessary on the part of the Air Navigator when making sextant observations. This dexterity can be acquired by anyone who practices enthusiastically. The bubble sextant, though widely used, is the more difficult instrument to master, since the bubble is affected by every jolt and twist of the aircraft in flight. Pilots should take note of these difficulties, because much laborious bubble-chasing can be saved by careful and conscientious flying. It is virtually impossible to obtain a good sight without active co-operation between the Pilot and the Navigator. Above all, the Pilot must maintain *Course and Airspeed* rigidly over the period of observation. If the aircraft tends to wander off the Course, or change its airspeed, it must be brought back to the original settings *by the end of the period of observation*. This naturally calls for a high proficiency in instrument-flying on the part of the Pilot; and pre-arranged signals warning him when to fly with especial care are of great practical value. Whenever provided, the Automatic Pilot should be used during astro observations.

21. With a Bubble Sextant, Mk. IX, the most satisfactory results are obtained by taking random shots at regular intervals of about 10 seconds over a period of 2 or 3 minutes. The Bubble Sextant, Mk. IX automatically averages the altitude of 6 "shots", and a series of three or four sets of 6 "shots" can be observed without interruption, the average value of the sight being obtained by dividing the Totalised Increment figure shown on the sextant by the number of sets, and adding this average increment to the coarse altitude on the sextant. If the "Increase" of 5° is in use, subtract 5° from The Totalised Increment reading before dividing by the number of sets. Then add the 5° again. Examine the last shot reading to decide whether to add any "tens" to the Totalised Increment shown.

Example :—

22. After taking 24 shots with a Mk. IX sextant, the Totalised Increment reads $9^{\circ} 04'$, 24 shots represents 4 sets of 6. The last shot read $8^{\circ} 40'$, with the 5° "Increase" in use. Therefore the Totalised Increment ought to read about $4 \times (8^{\circ} 40' - 5^{\circ}) + 5^{\circ}$, that is $(14^{\circ} 40' + 5^{\circ}) = 19^{\circ} 40'$. Evidently the Totaliser is reading 10° too little. Hence the proper increment is found to be $\frac{1}{4}(19^{\circ} 04' - 5^{\circ}) + 5^{\circ}$, namely $3^{\circ} 31' + 5^{\circ}$, or $8^{\circ} 31'$.

In practice it is simpler to jot down the result of each set of 6 shots, and to average them at the end.

It is most important not to wait for the bubble to "settle down", for when it appears to be most steady, it is, in fact, subject to the most prolonged and mischievous accelerations.

23. The Bubble Sextant, Mk. IXA is a greatly improved automatic averaging sextant, the operation of which is extremely simple: It averages 60 shots in 2 minutes, during which time the Navigator has to keep Body and Bubble together. Extremely accurate results are obtained.

24. To save trouble in averaging the Time of the Observation, once the Navigator is fairly adept, it is a good plan to start taking shots at a whole minute by the watch, and to finish if possible also at a whole minute. The middle time (for the sight) will then be at a whole minute or at a half-minute, if the period of observation is an even or an odd number of minutes respectively. Whenever possible, the Navigator should enlist the aid of a spare member of the crew (e.g., Second Pilot) who might note the time as the Navigator uses the sextant. Such division of labour will be found most helpful in the air.

Sextant Correction

25. Sextants are precision instruments, but there are limits to the accuracy with which any measurement can be made mechanically. When observing altitudes with a sextant, errors arise from :—

- (i) Faulty construction of the instrument.
- (ii) Wear and tear of the instrument.
- (iii) Personal Factor of the Navigator.

These defects are all equally difficult to detect, though to a large extent the first category is eliminated by careful tests made at the time of manufacture.

The first two categories result in an error which may vary both in quantity and in sign. For example, a sextant may read $2'$ too high at altitudes of about 40° , and $1'$ too low at altitudes of about 50° , and so on.

The personal factor of the Navigator is due to his unconsciously placing the observed body habitually, say, a little higher or lower than the exact centre of the bubble, or horizon. In one way or another no two Navigators will read a given scale-setting alike. However, once a Navigator is well accustomed to the use of a sextant, his personal factor may be regarded as being fairly stable in quantity and sign.

The sum total of all three sources of error is often variable according to the altitude observed. To compensate for this, a quantity called *Sextant Correction* must be applied algebraically to the observed altitude.

The most satisfactory way of determining Sextant Correction is for each Navigator to calibrate his own sextant. A large number of observations are made from known positions for altitudes at intervals of about 10° , up and down the scale, each "sight" being worked out and the error of its position line measured from the known position. When about 20 sets of sights have been observed at each altitude, their errors should be averaged. This average, *with the sign reversed*, may then be used as a correction to an observed altitude to make its position line pass through the Navigator's actual position.

Example :—

26. Twenty sights were observed at altitudes in the neighbourhood of 30° , and their position lines on the average were 5 n.m. from the known position, *towards* the Heavenly Bodies observed. In other words, the observed altitudes were all $5'$ too great (on the average). The appropriate Sextant Correction for observed altitudes of 30° was, therefore, $- 5'$.

27. When this rather protracted calibration is complete, the Navigator can draw up a critical table for Sextant Correction on the following lines. A curve of the Sextant Correction is drawn and the altitudes where the values of the Correction are half-minutes are found. These are the *critical altitudes*.

Example :—

28. After observing some 25 sights on altitudes approximately every 10°, from 20° to 70°, a Navigator obtains the following average Sextant Corrections, plotted as a curve :—

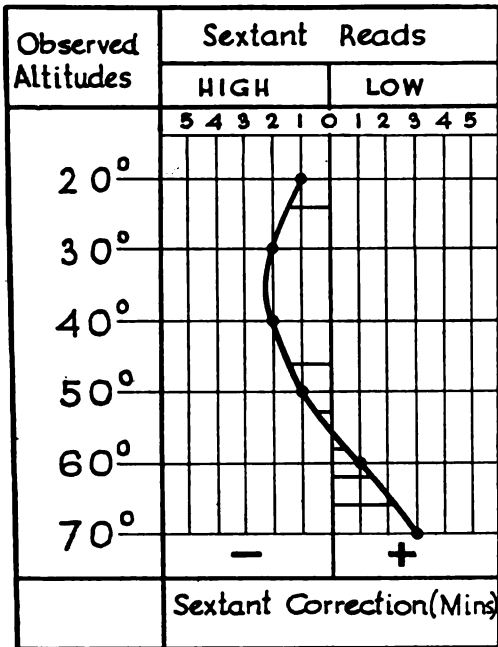


FIGURE 7. Tabulation of Sextant Correction.

Critical Table	
Between Altitudes	Apply to Sextant Readings
°	,
20-24	- 1
24-46	- 2
46-53	- 1
53-58	0
58-62	+ 1
62-66	+ 2
66-70	+ 3

The critical altitudes are extracted from the graph on the left and can be conveniently tabulated for use as in the Table on the right.

29. By taking pains to evaluate the correction to apply to his own sextant, a Navigator achieves three objects : Firstly, he obtains valuable data for subsequent observations with that sextant. Secondly, he gains confidence in his ability to obtain good results. Lastly, he learns to treat his sextant with the care that is its due.

Refraction

30. Rays of light from Heavenly Bodies are bent by refraction as they pass through the Earth's atmosphere, the density of which is greatest at ground level.

Figure 8 illustrates a typical example, and shows how the amount of refraction depends upon the altitude of the Body. Clearly, where the observed altitude is 90°, the ray (*A) is normal to the atmosphere and suffers no refraction ; while the refraction is most marked in the case of a ray (*B), roughly tangential to the atmosphere, that is, where the observed altitude is zero. In this case the Body is actually below the observer's horizontal when still visible.

The effect of refraction is to increase the apparent altitude of a Heavenly Body. To obtain a correct altitude, the value of refraction appropriate to the observed altitude should be subtracted from the observed altitude. In the *A.N. Tables* (A.P. 1618), average values for refraction are already incorporated in the tabulated altitudes, which are thereby made directly comparable with observed altitudes, without any allowance by the Air Navigator being necessary.

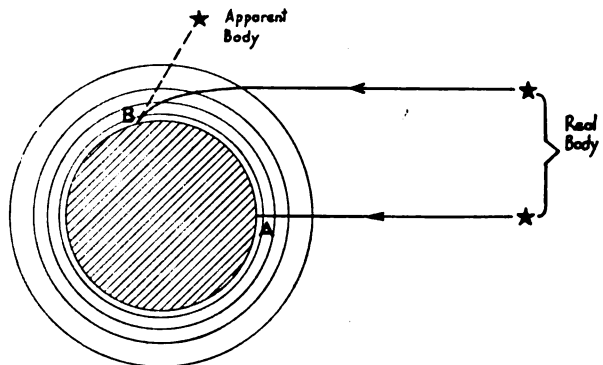


FIGURE 8. Refraction.

31. When observations are taken by the Air Navigator from inside an aircraft, the rays of light may be severely refracted in passing through the perspex or glass windows. Open hatches, optical glass "flats" and perspex Astro-domes have been designed to overcome this difficulty. Astro-domes are calibrated for refraction, which should be subtracted from observed altitudes. Standard figures for *Dome Refraction*, as it is called, are given on the Inside Front Cover, and on the Back Flap of the *Air Almanac*. These figures should only be used when none are provided for the particular Astro-dome in the aircraft.

Semi-Diameter

32. When using a marine-type sextant, the altitude of the Sun or Moon is most commonly measured by "bringing down" the reflected Body (seen through the sextant) until its lower limb is in grazing contact with the sea horizon. This is because of the difficulty of accurately bisecting the Body with the sea horizon. The correct altitude should be measured from the *centre* of the Body, and hence the altitude thus observed is too little by an amount equal to the Body's radius or semi-diameter. (See Figure 9.)

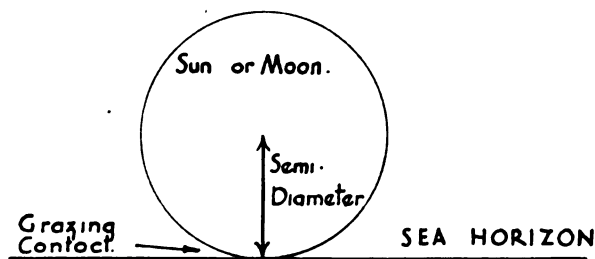


FIGURE 9. Semi-Diameter (Additive).

Diameter since one altitude is too little and the other too great by the amount of Semi-Diameter. Indeed, when possible, this is the best way to observe the Moon, which is seldom quite symmetrical.

The value of semi-diameter depends upon the nearness of the Sun or Moon at any moment. The Sun's semi-diameter is always 16', to the nearest minute. That of the Moon varies between 15' and 17'. Both are tabulated daily in the *Air Almanac*.

If, in addition, the upper limb of the Body is brought down until it is in grazing contact with the sea horizon, and the two observations averaged, there is no need to apply Semi-

Dip

33. When using a marine-type sextant, altitudes are measured from the sea horizon, which is assumed to be in the true horizontal plane of the Navigator. This, however, is only so when the Navigator is at sea level. From any height above sea level the sea horizon is below the horizontal by an angle called *Dip*. (See Figure 10.)

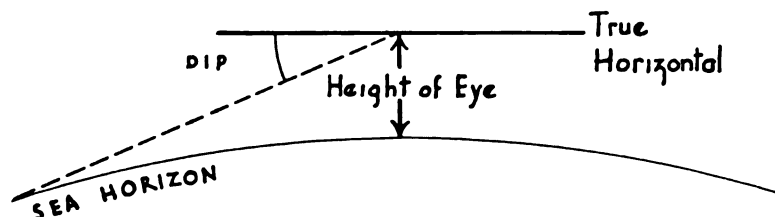


FIGURE 10. Dip of the Horizon.

The value of Dip of the sea horizon obviously depends on the Navigator's height above sea level. Altitudes observed against the sea horizon are thus too great, and Dip must be subtracted from the observed altitude. Dip is tabulated in the *Air Almanac* and also in the *A.N. Tables*.

Parallax in Altitude

34. The Moon is not sufficiently distant from the Earth for its rays of light to be parallel at the Earth. The foregoing assumption that the observed altitude of a Heavenly Body is the complement of the radius of the observer's position circle is, therefore, not accurate enough in the case of Moon sights.

In fact, the observed altitude is smaller by an amount called *parallax in altitude* (P. in A.), than if the rays of light were parallel. Figure 11 illustrates this point.

M is the Moon ;
O is the centre of the Earth ;
X is the sub-stellar point ;
Z is an observer ;

MX, MZ are actual light rays from the Moon ;
M'Z is parallel to MX ;

HH is the true horizontal at Z ;

Angle HZM is the observed altitude of the Moon ;

Angle HZM' is the corrected altitude (as if the rays from the Moon were parallel) ;

∴ Angle MZM' is the difference between observed altitude and true altitude of the Moon.

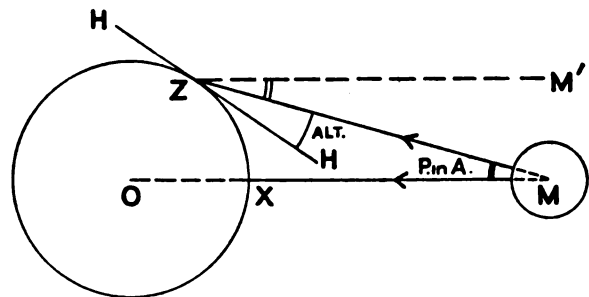


FIGURE 11. Parallax in Altitude.

Evidently the nearer Z is to X, the smaller this difference will be. This corresponds to an increase in observed altitude. Tables are provided in the *Air Almanac* to give the actual value of Parallax in Altitude that has to be *added* to any particular observed altitude of the Moon to obtain its True altitude.

Z Correction

35. Even when maintaining a perfectly steady Course and Airspeed a bubble does not provide a true datum for measuring altitudes, for reasons explained in A.P. 1456, *Manual of Air Navigation, Volume II*. Moreover, it is impossible to fly perfectly, and an allowance for Change of Course over the period of observation is necessary when using a bubble sextant.

36. This error is caused by the wander of the aircraft due to gyro precession (when steering by Directional Gyro or on Automatics), and by the aircraft constantly turning while in flight (due to the earth rotating), even though its track relative to the earth is quite straight. The first error can be eliminated by steering on the D.R. Compass, which should never be more than 1° out, but the second error must be allowed for.

37. The altitude of a Heavenly Body observed by a bubble sextant in flight may be too high or too low by an amount called Z, which depends on the ground speed and latitude of the aircraft. Since both these are known within reasonable accuracy, the value for Z may be extracted from the *Air Almanac*.

38. It must be thoroughly understood that careful flying is *essential* for good astro observations. The Navigator must warn the Pilot before, and immediately after taking sights. If available, an Automatic Pilot should be used by night. By day, a D.R. Compass provides the best steering datum as it is free from precession ; but unless the Pilot is skilful it may be preferable to use the Automatic Pilot at all times. The Pilot must make every effort to return to the original settings of Airspeed and Compass Course by the end of the observations, and should report any discrepancies to the Navigator after the observations have been made.

Selection of Bodies for Fixing Position

39. (i) By Day

Except for a few days in the First and Last Quarters of the Moon, when both Sun and Moon may be visible, the Air Navigator at present has no choice of Heavenly Bodies by day, though the observation of stars and planets by day may yet be developed.

If only the Sun is available, its change of azimuth (most rapid about local noon) may be put to good use. For example, if the True azimuth of the Sun is 165° at 11.30 hours G.M.T. in a certain place, and at 14.30 hours G.M.T. it is 205° , the two position lines can be used to fix the position with fair accuracy since they are inclined at an angle of 40° and will make a good "cut". If an aircraft is travelling eastwards, the change of azimuth will be accelerated, and *vice versa* if it is travelling westwards. Since, however, the two Position Lines are obtained over a period of at least 3 hours, the error in D.R. position may be considerable. This method, therefore, is not to be recommended for obtaining fixes.

(ii) By Night

There is no difficulty at night in selecting Heavenly Bodies whose azimuths differ sufficiently to give a satisfactory "cut" between their position lines. It is of interest to note that when using the

Astrograph (*see* paragraph 42), the selection of suitable stars is already made for the Air Navigator who simply has to observe those stars for which the curves are drawn on that part of the Astrograph film in use.

The Astrograph

40. It has already been stated that a sub-stellar point may be located for any instant of time and that circles drawn from this common centre with various radii are position circles corresponding to various observed altitudes of the Body. These concentric position circles move with the sub-stellar point over the face of the Earth from East to West as the Earth rotates from West to East.

41. If a film were made upon which position circles were drawn for such stars as would be visible at various times in a certain locality, and these circles were thrown by a projector on to a map of the locality, then by turning the film from East to West to keep the centres of the curves co-incident with the appropriate sub-stellar points, the projected curves could be used as a visual guide for plotting actual position lines from the *observed* altitudes of the selected stars. This is what the Navigator does when using an Astrograph.

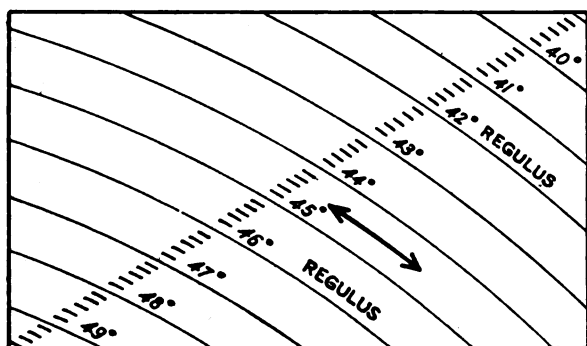


FIGURE 12.
Astrograph Projection of Altitude Curves.

Figure 12 represents a sheet of G.S.G.S. 4080 upon which arcs of position circles are projected by Astrograph for the star REGULUS. When suitably adjusted for the G.M.T. of Observation (a Time-Scale on the film is aligned with an appropriate meridian on the chart) the centre of the projected arcs is in fact coincident with the proper sub-stellar point of REGULUS. Suppose an altitude of $44^{\circ} 30'$ of REGULUS is observed. The actual position line is drawn in pencil by the Navigator half-way between the projected arcs of altitudes $44^{\circ} 00'$ and $45^{\circ} 00'$ as shown above. Graduations every $10'$ of altitude assist visual interpolation between the curves projected.

42. The Astrograph film always gives arcs of altitude for two stars and, in addition "Q" corrections for POLARIS observations where these are possible (*see* paragraph 17). As a result, the Navigator can plot three position lines with great rapidity and little effort, and by transferring two for the short "run" between the times of observations (*see* Chapter VI, paragraph 26) he obtains a three-star fix that will be as accurate as his observations have been skilful.

43. If it is desired to identify the particular stars used by the Astrograph at any time, the projected curves are adjusted for the time in question, and the altitude and azimuth (at right-angles to the curves, in the direction of *increasing* altitude) are then read off in the vicinity of the D.R. position.

44. In practice the projected curves are kept in step with the movement of the sub-stellar points by setting an appropriately converted Time reading on the central Time-Scale against a Setting Longitude on the map. The Setting Longitude and Conversion for G.M.T. are derived from the Astrograph Tables printed in the *Air Almanac*.

Instructions for Operating the Astrograph

45. (i) Preparation of Plotting Maps before Flight :—

- (a) Open the *Air Almanac* at the Astrograph Tables for the night of the intended flight (Local Dates).
- (b) Construct a Time Conversion Table at the Setting Longitude plainly marked on each chart sheet to be used.

(ii) Preparation of the Astrograph :—

- (a) Fit the spool of film appropriate to the plotting sheet to be used.
- (b) Switch on the Astrograph.
- (c) Rotate one of the two large wheels in front of the instrument until the correct band of curves for the Latitude of the plotting map is projected on the chart.

(d) Pin down the plotting map to the table so that its three thick Latitude lines are parallel to the three Latitude lines projected by the Astrograph.

(e) By means of the central knob adjust the projected Latitude lines N or S so as to coincide with the corresponding ones on the plotting chart. All three lines will coincide only when the magnification is correct.

(f) Switch off.

(iii) *To obtain a Fix :—*

(a) Note the G.M.T. as a whole number of hours only, neglecting odd minutes.

(b) Opposite this whole number of hours of G.M.T. in the Time Conversion Table (i) (b) read off the corresponding complete hour of Astrograph Time.

(c) Switch on the Astrograph.

(d) By rotating one of the two large wheels in front of the instrument, adjust the Time-Scale projected on the central Latitude so that the complete hour of Astrograph Time (iii) (c) is set against the marked meridian. This amounts to adjusting the instrument for the G.M.T. of Observation and thereafter the hours figures of time may be ignored. (See sub-paragraph (l) below.)

(e) Note the names and positions of the stars whose altitude curves cover the D.R. position. If it is seen that the stars are about to change, wait for, say, ten minutes. This will save time and avoid observing a star that is not catered for by the film.

(f) Switch off the Astrograph.

(g) Observe the altitude of the first star and the G.M.T.

(h) Observe the altitude of second star and the G.M.T.

(i) Apply Sextant Correction to the sextant readings.

(j) If observations were made through an Astro-dome, subtract from the observed altitudes the correction for Dome Refraction.

(k) When applicable, correct the sextant readings for **Z** (see paragraph 35).

(l) Switch on the Astrograph. Adjust the projected Time-Scale so that the minutes and seconds of the G.M.T. of the first observation are brought opposite the marked meridian.

(m) Near the D.R. position draw with the aid of the projected shadows a position line corresponding to the observed altitude of the first star.

(n) Repeat (l) and (m) for the observation of the second star.

(o) Switch off the Astrograph.

(p) The intersection of the second position line with the first, transferred for the distance run between the lines of observation constitutes the fix.

(iv) *To obtain Latitude as a Check :—*

(a) Observe POLARIS and correct with Sextant Correction and for Dome Refraction if necessary. If applicable, correct for **Z** (see paragraph 35).

(b) Switch on the Astrograph.

(c) Adjust the projected Time-Scale so that the minutes and seconds for the G.M.T. of observation are opposite the marked meridian.

(d) Against the **D.R. Longitude** read the "Q" Correction, printed at intervals above the projected Time-Scale.

(e) Switch off the Astrograph.

(f) Apply "Q" to the observed altitude of POLARIS, to obtain the Latitude, and mark in this Latitude as another position line, transferred if necessary forwards or backwards for the run between the G.M.T. of observation and the G.M.T. of the two-star fix.

Obtaining Astro Position Lines using the Air Almanac and Astronomical Navigation Tables

46. The calculation of astro position lines is very much simplified for the Air Navigator by the tabulation of information in a convenient manner. Nevertheless, some little practice is required before an Air Navigator can find the way faultlessly and without effort through the various phases of the process. Beginners and those who lack recent practice will find Form 1519 a useful means of picking up the correct procedure for dealing with observations of various Heavenly Bodies. Once proficiency has been attained, a small piece of blank paper, such as a message slip, is often more handy than a prepared form. However, the Air Navigator may wish to use F.1519 as a permanent record of his sights. In any case the procedure outlined in F.1519 is fundamental, and consequently must be examined in detail, whether or not the Form is used.

47. Apart from its heading, Form 1519 has four main aspects : It has two vertical divisions, the left-hand side being concerned with Time, and the right-hand side with Altitude. Again, each column is divided horizontally roughly into two : the upper half is for recording Observations, while the lower half is for Calculations. Each of these aspects is taken in a definite order by the Navigator so as to minimise reference to books and to avoid duplication of work.

48. Before going into details it should be noted that when working on the lower, " Calculation " half of the Form, the *Air Almanac* is used first and then discarded once and for all, and the appropriate volume of *A.N. Tables* is then opened. At no time is it necessary to refer to both books together.

49. Because the procedure differs slightly with the various Bodies observed, it is convenient to have separate Forms for separate categories of Bodies. In addition the procedure when using a Marine Sextant is different from that when a Bubble Sextant is used and a separate Form is provided for this case.

Each Form will now be considered in turn.

Form 1519A

50. This Form is designed for use with STARS (Nos. 1-22) for which a simplified procedure is given in the *A.N. Tables*. (See Figure 13.)

(i) Heading

- | | | | | |
|----------------------------------|----------------------|-----|-----|--|
| (a) ★ No.... | ... | ... | ... | The Number of the Star is recorded here. It is the same as the Page Number in the <i>A.N. Tables</i> to which reference is made later. |
| (b) <i>Approximate Latitude</i> | ... | | | This is required to the nearest degree of D.R. Latitude. Strike through " N " or " S," whichever does not apply. The approximate Latitude is used later as an argument for entering <i>Z Table</i> and the <i>A.N. Tables</i> . |
| (c) <i>Approximate Longitude</i> | ... | | | This is required to the nearest degree of D.R. Longitude. Strike through " E " or " W," whichever does not apply. The approximate Longitude helps in choosing an Assumed Longitude for calculating the Hour Angle. See (iv) (e). |
| (d) <i>Ground Speed...</i> | ... | ... | ... | This is required as an argument for <i>Z</i> . |
| (e) <i>Z Correction</i> | ... | ... | ... | This is the displacement in nautical miles of the Position Line at right angles to the Track ; to the right in North Latitudes, to the left in South Latitudes. |
| (f) <i>Sextant No.</i> | (g) <i>Navigator</i> | ... | ... | These are required for compiling data on Sextant Correction. (See paragraphs 25-29.) |

(ii) Recorded Time

- | | | | | |
|----------------------------------|-----|-----|-----|--|
| (a) <i>Watch Reading Average</i> | ... | | | Navigation should always be conducted in G.M.T., so that there will be no ambiguity in watch reading when using a watch with a normal 12-hour dial. The Average Watch Reading is the mean or, alternatively, the middle time of the observation. |
| (b) <i>Watch Error</i> | ... | ... | ... | The Watch Error is applied, striking out " Fast - " or " Slow +," whichever does not apply. |
| (c) <i>G.M.T. of Observation</i> | ... | | | This is the argument for extracting the correct Hour Angles from the <i>Air Almanac</i> . It is also used when plotting the position line, and is consequently <i>underlined</i> . |

(iii) Recorded Altitude

- | | | | | |
|------------------------------------|-----|-----|-----|--|
| (a) <i>Sextant Reading Average</i> | ... | | | The Navigator now records the Sextant Reading Average indicated on his sextant. |
| (b) <i>Sextant Correction</i> | ... | ... | ... | The Sextant Correction is then applied, and the sign not applicable is struck out. |
| (c) <i>Dome Refraction</i> | ... | ... | ... | If the sight was taken through a perspex astro-dome, the Dome Refraction applicable to the Sextant Reading is subtracted, to obtain the Corrected Observed Altitude. |

(iv) Calculated Hour Angle

- (a) *G.H.A. γ* Open the *Air Almanac* (from which the pages have been torn, until the current Greenwich Date is uppermost). Extract the G.H.A. γ for the G.M.T. of observation, to the nearest 10 minutes *less* than the actual G.M.T. of observation.
- (b) *Increment γ* At the same time, extract from the Inside Front Cover, the Increment of G.H.A. γ , corresponding to the odd minutes and seconds of the G.M.T. of observation.
- (c) *S.H.A. $\star$* At the same time, extract from the Inside Front Cover the S.H.A. of the Star in question.
- (d) *G.H.A. $\star$* This is the sum of (a), (b) and (c) above.
- (e) *Assumed Longitude* Assume a Longitude reasonably close to the Approximate Longitude, (i) (c), which, when applied to the G.H.A. $\star$, will give an exact number of degrees. (See paragraph 13.) Strike out the name and sign not applicable.
- (f) $+ 360^\circ$ If the Assumed Longitude is West, and is seen to exceed the G.H.A. $\star$, add 360° to the latter before applying to the Longitude.
- (g) $- 360^\circ$ If the Assumed Longitude, applied to G.H.A. $\star$, gives a number in excess of 360° , subtract 360° . The result is the (L.)H.A. $\star$

(v) Calculated Intercept

- (a) *Assumed Latitude* Assume a Latitude, usually Approximate Latitude (i) (b). This is used in the plotting of the Position Line.
- (b) *Ground Speed...* Write down the Ground Speed.
- (c) *Z Correction* Enter **Z Table** in the *Air Almanac* with (v) (a) and (b) above, and record the extract in nautical miles.

NOW DISCARD THE AIR ALMANAC

- (d) *A.N. Table* Open the *A.N. Table* at the page of the Star Number, (i) (a), appropriate to the Name of the Assumed Latitude, (i) (b).
- (e) *Tabulated Altitude, t , and Tabulated Azimuth.* Against H.A. $\star$, (iv) (g), and Assumed Latitude, (v) (a), extract Tabulated Altitude, t (+ or -) and Tabulated Azimuth. Write these in the spaces provided. Look at the Footnote to see if Correction for Date is necessary. Note also whether the H.A. is tabulated on the LEFT or RIGHT-hand side of the page.
- (f) *Correction for Date* If a Correction for Date is necessary, turn to *A.N. Table I*. In the column for t , extract the Correction against the Year. Its sign is the same as for t . Strike out the non-applicable sign.
- (g) *Corrected Tabulated Altitude* The Corrected Tabulated Altitude is written in the main column under the Corrected Observed Altitude. The difference between these two altitudes is the Intercept (underlined for plotting).
- (h) *Intercept* The Intercept is named "Towards" or "Away" if the Observed Altitude is greater or less than the Tabulated Altitude respectively. Strike out the name that does not apply.
- (i) *True Azimuth* Following the rule at the foot of the open page of the *A.N. Tables*, convert the Tabulated Azimuth to a True Azimuth by writing 360° or 180° , if necessary, and applying the Tabulated Azimuth in the way appropriate to the H.A. $\star$ (LEFT or RIGHT).

(vi) **Plotting.**—All the data for Plotting are *underlined* on the Form.

- Mark the Assumed Position on the map.
- Through this point draw a line in the direction of the True Azimuth.
- Lay off along this line a distance in NAUTICAL MILES equal to the Intercept, from the Assumed Position, either in the direction of the Star (if the Intercept is "Towards"), or away from the Star (if the Intercept is "Away").
- Through the point thus obtained, draw a line at right-angles to the Azimuth line, displace this Position Line at right-angles to the Track, to the right in the North Lat., to the left in the South Lat., by the amount of the **Z** Correction. Extend this second Position Line as convenient, and record G.M.T. against it.

THE D.R. POSITION IS NOT USED IN THE PLOTTING

STARS (NOS. 1-22)		GREENWICH DATE <u>1st APRIL 1944</u>		FORM 1519 A	
* NUMBER	APPROX LAT. <u>53° N</u>	GROUND SPEED <u>260</u> KNOTS	SEXTANT No.	NAVIGATOR	
<u>18</u>	APPROX LONG <u>33° W</u>	LATITUDE <u>53° N or S</u>	<u>433/43</u>	<u>F/O STIRLING</u>	
		Z CORRECTION <u>5</u> n.m.			

WATCH READING AVERAGE		HOURS	MIN.	SECS
"	" <u>SLOW</u> →	21	35	10
"	" <u>FAST</u> ←			15
G.M.T. OF OBSERVATION		21	34	55

SEXTANT READING AVERAGE		0	1
SEXTANT CORRECTION		18	44
DOME REF. (if applicable) -		18	42
CORRECTED OBSERVED ALT.		18	35
TABULATED ALT. <u>18</u> <u>45</u>		18	45
CORRECTED TABULATED ALT.		18	45
INTERCEPT		10'	
OBS. ALT. > TAB. ALT.		<u>TOWARDS</u>	
OBS. ALT. < TAB. ALT.		<u>AWAY</u>	

AIR ALMANAC		0	1
G.H.A. *	+	152	37
INGREMENT *	+	1	14
S.H.A. *	+	282	02
G.H.A. *		435	53
+ 360° (if necessary)		-	-
ASSUMED LONG <u>E</u> +		32	53
<u>W</u> -		403	
- 360° (if necessary)		360	
(L) H.A. *		43°	

ASSUMED LAT. <u>53° N</u>	
Z CORRECTION	
DISPLACE POSITION LINE AT RIGHT ANGLES TO TRACK	
TO RIGHT OF TRACK IF <u>NORTH</u> LATITUDE	
TO LEFT OF TRACK IF <u>SOUTH</u> LATITUDE	

360° OR 180° (if necessary)	
TAB AZIMUTH	360°
TRUE AZIMUTH	135°
	225°

L 1425 30955 P 1026, 100, 11/42

FIGURE 13(a). Form 1519A, showing worked example of a star (No. 1-22) observation.

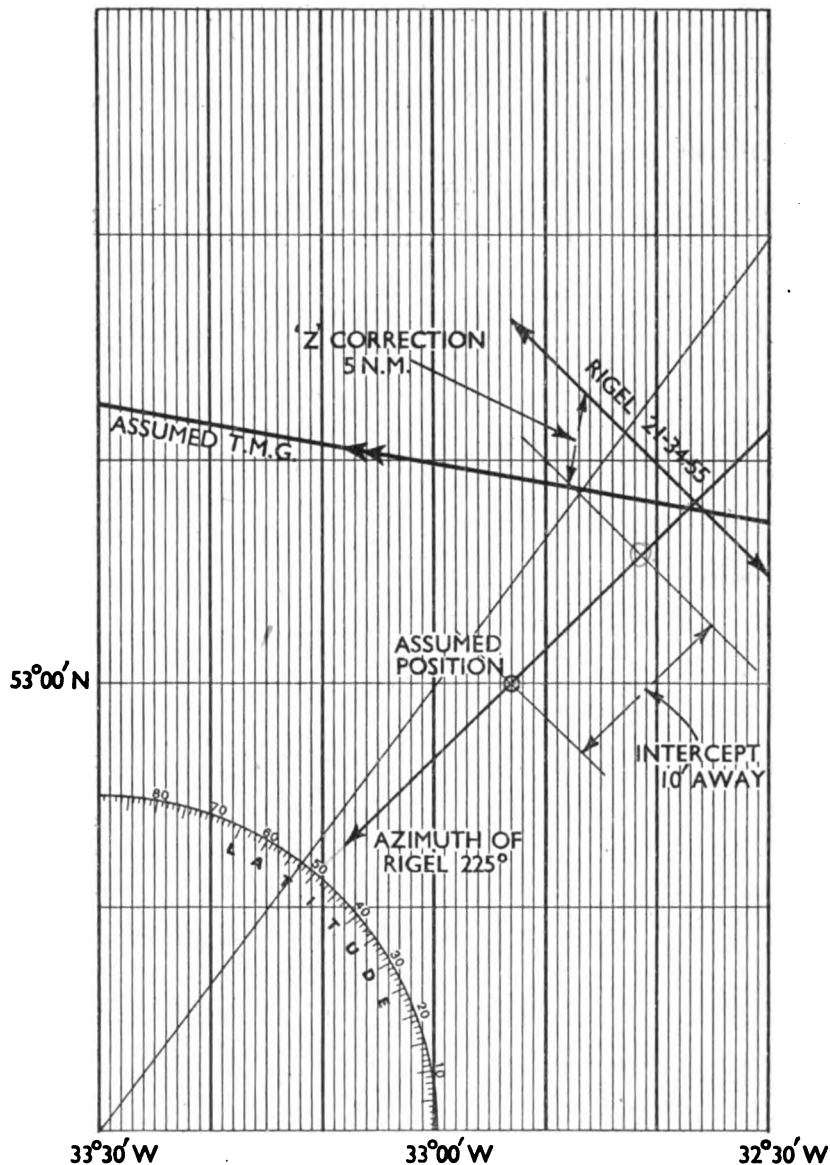


FIGURE 13(b). Star position line plotted from worked example.

To construct a local Mercator graticule for use instead of a map when plotting a position line : Regard the small divisions as minutes of longitude. Draw a line outwards from the centre of the quadrant through the Assumed Latitude. The scale of latitude and therefore of distance in nautical miles at the Assumed Latitude is given by the length of this line intercepted by the longitude divisions. Select the most convenient horizontal line as the parallel in question.

51. This is an Omnibus Form, designed for use with the SUN, MOON, PLANETS or STARS (Nos. 23-35). It is very similar to Form 1519A. (See Figures 14 and 15.)

(a)-(g) See F.1519A, (i) (a)-(g).

(a)-(c) See F.1519A, (ii) (a)-(c).

(a)-(c) See F.1519A, (iii) (a)-(c).

(d) P. in A. If the moon is observed, extract and apply the value for Parallax-in-Altitude from the *Air Almanac*.

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FIGURE 14(a). Form 1519B, showing worked example of a planet observation.

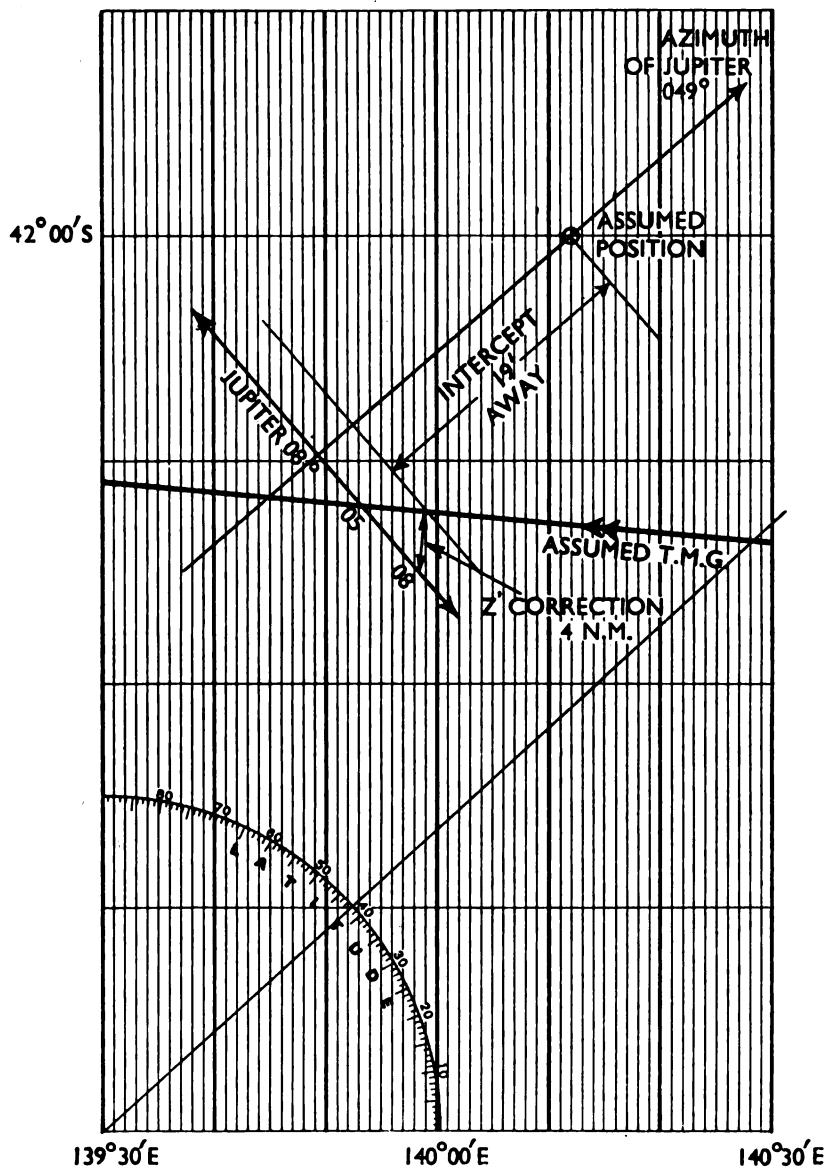


FIGURE 14(b). Planet position line plotted from worked example.

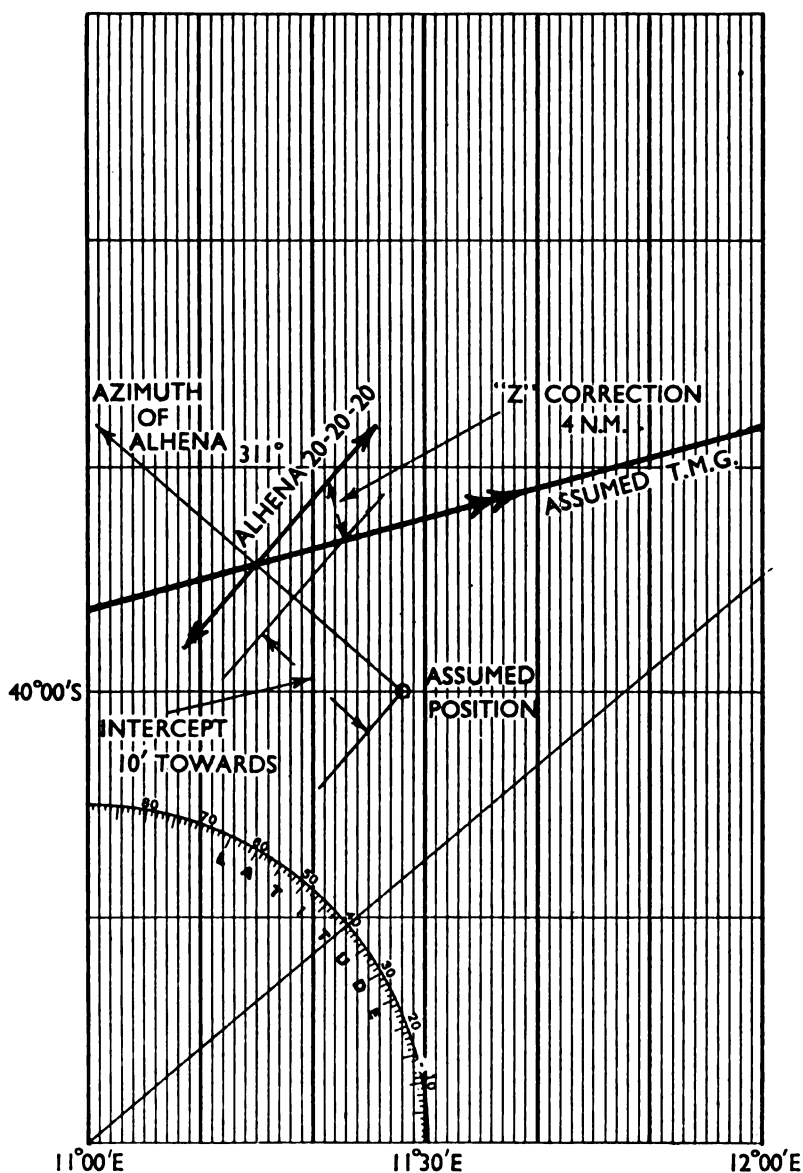


FIGURE 15(b). Star position line plotted from worked example.

All Bodies—

(g) *Declination* ... While the *Air Almanac* is open, extract the Body's Declination and Name, and write it in the space provided. Strike out "N" or "S" whichever does not apply.

(h)–(k) ... See F.1519A, (iv) (e)–(g).

(v) Calculated Intercept

(a)–(c) ... See F.1519A, (v) (a)–(c).

NOW DISCARD THE *AIR ALMANAC*

- (d) Open the *A.N. Table* at the same page of the Declination in degrees (iv) (i), either the SAME (name) or CONTRARY (name), compared with the name of the Latitude.
- (e) Against the H.A. Body extract from the proper Latitude column the Tabulated Altitude, d (+ or -) and Tabulated Azimuth. Enter these in the spaces provided. Note also whether the H.A. is tabulated on the LEFT or RIGHT-hand side of the page.
- (f) *Correction (for minutes of Declination).* Turn to *A.N. Table XV*. In the column for d , extract the Correction against the minutes of Declination, (iv) (i), not yet taken into account. Its sign is the same as for d . Strike out the non-applicable sign.
- (g)-(i) See F.1519A, (v) (g)-(i).
- (vi) **Plotting**
- (a)-(d) See F.1519A, (vi) (a)-(d).

POLE STAR		GREENWICH DATE 1ST APRIL 1944		FORM 1519 C	
APPROX. LAT.	D.R. LONG.	GROUND SPEED 260 KTS.	SEXTANT No.	NAVIGATOR	
50° N	58° 10' W	LATITUDE 50° N.	015657	F/O WHITLEY	
		Z CORRECTION 5 n.m.			

WATCH READING AVERAGE " " SLOW + G.M.T. OF OBSERVATION	<table border="1" style="margin: auto;"> <tr><th>HOURS</th><th>MINS</th><th>SECS.</th></tr> <tr><td>01</td><td>42</td><td>19</td></tr> <tr><td></td><td></td><td>57</td></tr> <tr><td>01</td><td>43</td><td>16</td></tr> </table>	HOURS	MINS	SECS.	01	42	19			57	01	43	16	SEXTANT READING AVERAGE SEXTANT CORRECTION + DOME REFN (if applicable) - CORRECTED OBSERVED ALT LATITUDE	<table border="1" style="margin: auto;"> <tr><th>°</th><th>'</th></tr> <tr><td>49</td><td>37</td></tr> <tr><td></td><td>2</td></tr> <tr><td>49</td><td>35</td></tr> <tr><td></td><td>4</td></tr> <tr><td>49</td><td>31</td></tr> <tr><td></td><td>38</td></tr> <tr><td>50</td><td>09</td></tr> </table>	°	'	49	37		2	49	35		4	49	31		38	50	09
HOURS	MINS	SECS.																													
01	42	19																													
		57																													
01	43	16																													
°	'																														
49	37																														
	2																														
49	35																														
	4																														
49	31																														
	38																														
50	09																														

AIR ALMANAC { G.H.A. T INCREMENT + + 360° (if necessary) D R LONG W - 360° (if necessary) L.H.A. T	<table border="1" style="margin: auto;"> <tr><th>°</th><th>'</th></tr> <tr><td>214</td><td>18</td></tr> <tr><td></td><td>49</td></tr> <tr><td>215</td><td>07</td></tr> <tr><td>-</td><td>-</td></tr> <tr><td>58</td><td>10</td></tr> <tr><td>156</td><td>57</td></tr> <tr><td>-</td><td>-</td></tr> <tr><td>156</td><td>57</td></tr> </table>	°	'	214	18		49	215	07	-	-	58	10	156	57	-	-	156	57	Q TABLE AIR ALMANAC
°	'																			
214	18																			
	49																			
215	07																			
-	-																			
58	10																			
156	57																			
-	-																			
156	57																			

Z CORRECTION DISPLACE POSITION LINE AT RIGHT ANGLES TO TRACK TO <u>RIGHT</u> OF TRACK IN <u>NORTH</u> LATITUDE

L.1425

FIGURE 16(a). Form 1519C, showing worked example of a Polaris observation.

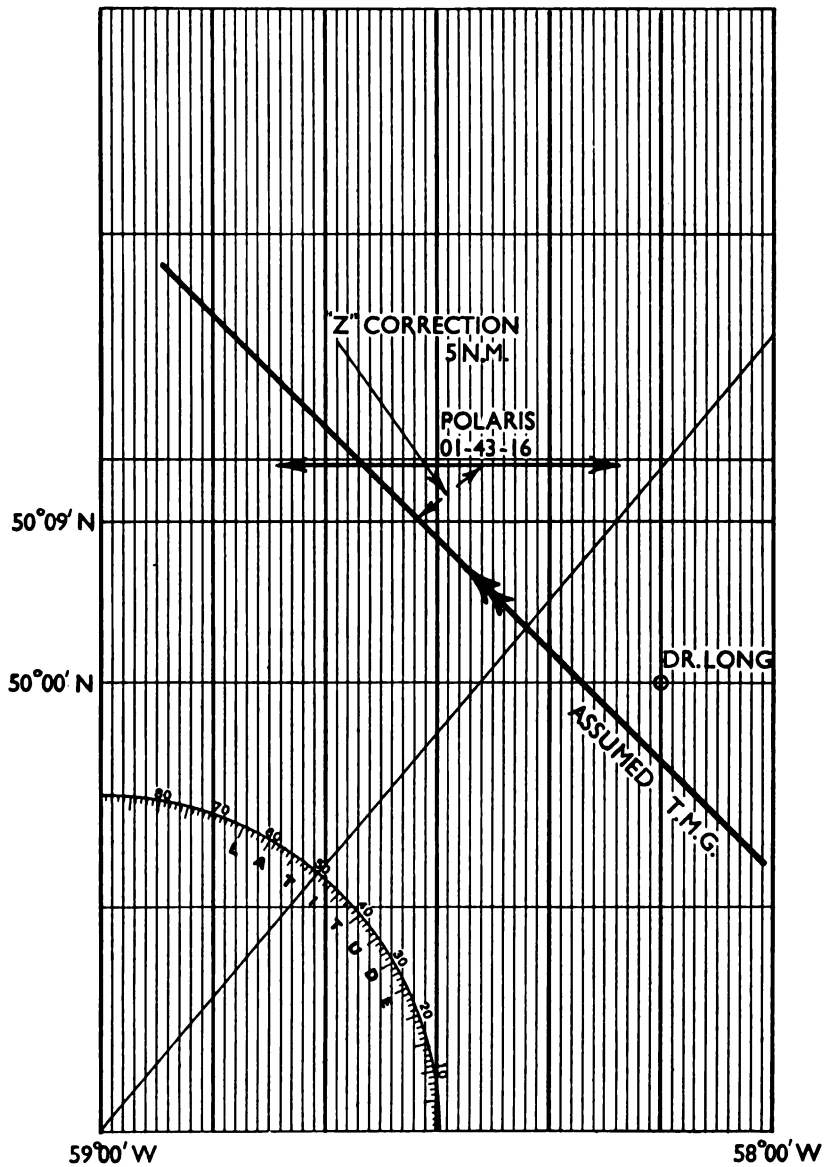


FIGURE 16 (b). Polaris sight plotted from worked example.

Form 1519C

52. This Form is designed only for POLARIS sights, for which a very simple procedure is possible. (See Figure 16.)

(i) **Heading**

This differs from that of F.1519A or B in that it applies to observations of only one star. More significant, however, is the fact that the **D.R. Longitude** is required (in degrees and minutes) instead of only an approximate Longitude.

(ii) **Recorded Time**

(a)-(c) See F.1519A, (ii) (a)-(c).

(iii) **Recorded Altitude**

(a)-(c) See F.1519A, (iii) (a)-(c).

(iv) **Calculated Hour Angle**

(a) and (b) See F.1519A, (iv) (a) and (b).

(c) *D.R. Longitude* Enter the D.R. Longitude. Strike out the name and sign not applicable.

SUN, MOON, PLANETS. (MARINE SEXTANT) 1 ST APRIL 1944						FORM 1519 D
BODY	APPROX. LAT. <u>44° N</u>	HEIGHT	LIMB OBSERVED		SEXTANT NO.	NAVIGATOR
SUN	APPROX. LONG. <u>2° E</u>	2,000	UPPER <u>-</u>	LOWER <u>+</u>	K 1439	F/O ANSON

WATCH READING		HOURS	MIN.	SECS.
		10	40	35
SLOW +				20
FAST -				
G.M.T. OF OBSERVATION		10	40	55

AIR ALMANAC		°	'
G.H.A. BODY	+	339	01
INCREMENT			14
G.H.A. BODY	+	339	15
+ 360° (if necessary)			
ASSUMED LONG <u>E</u> +		1	45
<u>W</u> -		341	
- 360° (if necessary)			
(L) H.A. BODY		341	

(AIR ALMANAC) DEC.		°	'	N	S
ASSUMED LAT	<u>44° N</u>	4	35		

SEXTANT READING AVERAGE		°	'
		47	49
SEXTANT CORRECTION <u>+</u>			3
		47	52
DOME REFN. (if applicable) <u>-</u>			NIL
		47	52
DIP <u>-</u>			44
		47	08
SEMI-DIAMETER <u>+</u>			16
		47	24
P IN A (Moon only) <u>+</u>			-
CORRECTED OBSERVED ALT.		47	24
TABULATED ALT. <u>46</u> <u>39</u>			
d ± .56 CORN. <u>+</u>			33
CORRECT TABULATED ALT.		47	12
INTERCEPT			12
OBS. ALT. > TAB. ALT.		TOWARDS	
OBS. ALT. < TAB. ALT.		~~AWAY~~	
360° OR 180° (if necessary)			
TAB. AZIMUTH		±	152
TRUE AZIMUTH			152°

FIGURE 17 (a). Form 1519D, showing worked example of a sun observation.

(iv) **Calculated Hour Angle—contd.**

- (d) $+360^\circ$ If the Longitude is West, and it is seen to exceed the sum of (a) and (b), add 360° before subtracting the Longitude.
- (e) -360° If necessary, subtract 360° to reduce L.H.A. γ below 360° .

(v) **The Latitude**

- (a)-(c) See F.1519A, (v) (a)-(c).
- (d) Q Enter the Q Table in the *Air Almanac* with L.H.A. γ , and extract the corresponding value and sign for Q . Strike out the sign not applicable.
- (e) *Latitude* Apply Q to the Corrected Observed Altitude to obtain the Latitude (always North).

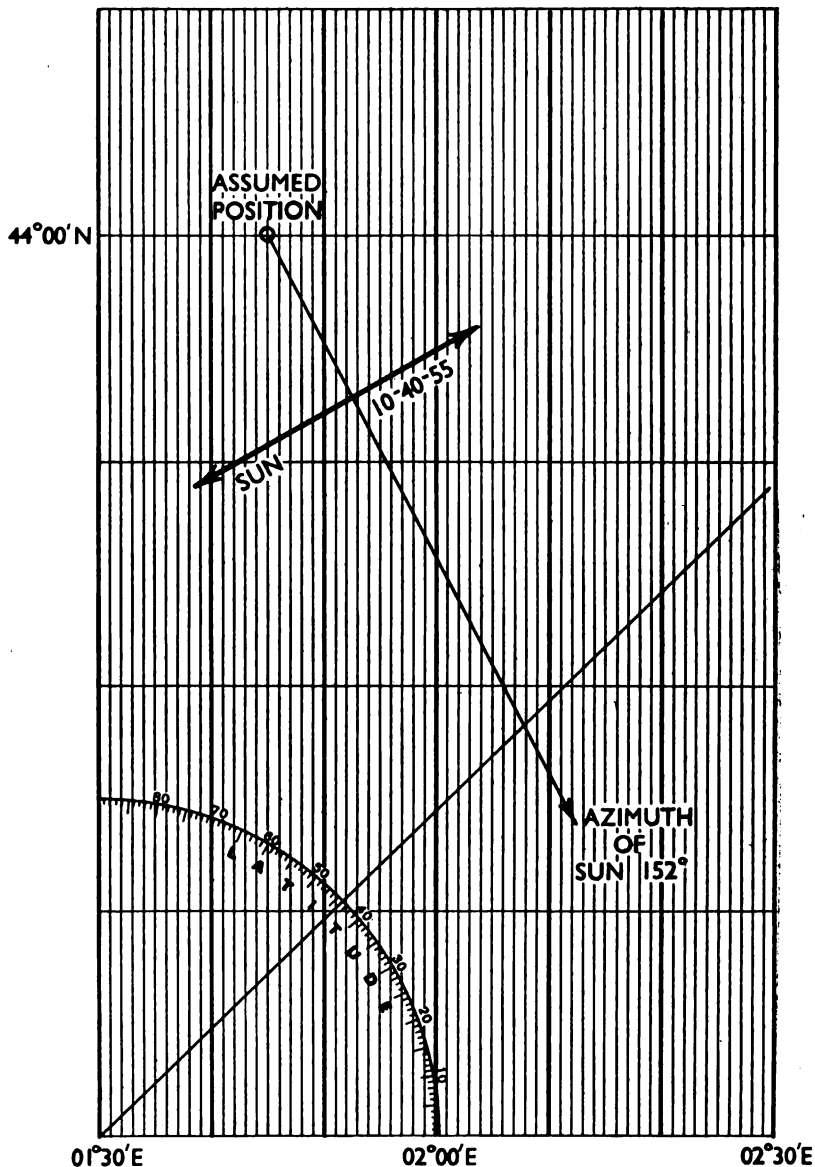


FIGURE 17 (b). Sun position line plotted from worked example.

Form 1519C—contd.**(vi) Plotting**

This consists simply of drawing a parallel of Latitude on the map at the Latitude found above, displacing it to the right of the track by the amount of *Z* Correction. The Time should be recorded against it.

Form 1519D.

53. This is designed for use when observing the SUN, MOON or PLANETS with a Marine Sextant.

(i) Heading

(a)–(c) See F.1519A, (a)–(c).

(d) *Height* This is recorded in feet above the level of the horizon used (normally the sea). It is an argument used for finding Dip.

(e) *Limb Observed* The sign of Semi-Diameter is Plus or Minus, according to which Limb is observed. The sign not applicable is struck out.

(f) and (g) See F.1519A, (i) (f) and (g).

(ii) Recorded Time

(a)–(c) See F.1519A, (ii) (a)–(c).

(iii) Recorded Altitude

(a)–(d) See F.1519B, (iii) (a)–(d).

(iv) Calculated Hour Angle

(a)–(h) See F.1519B, (iv) (a)–(d) and (i)–(I).

(v) Calculated Intercept

(a) See F.1519A, (v) (a).

(b) *Dip* Against Height, extract from the *Air Almanac* the value of Dip, which is always subtracted.

(c) *Semi-Diameter* From the *Air Almanac* extract the value of Semi-Diameter for the day, and strike out whichever sign does not apply.

NOW DISCARD THE *AIR ALMANAC*

(d)–(i) See F.1519B, (v) (d)–(i).

(vi) Plotting

(a)–(c) See F.1519A, (vi) (a)–(v).

(d) Through the point thus obtained, draw a line at right angles to the Azimuth Line. Extend this line as convenient for use as a Position Line, and record the G.M.T. against it.

STARS, JANUARY—APRIL, 1944

No.	Name	Adopted abbreviation	Mag.	S.H.A.	Dec.	American Air Almanac Name
1	ACHERNAR	ACHER	0.6	336 06	S. 57 31	Achernar
2	ACRUX	ACRUX	1.1	174 08	S. 62 47	Acrux
3	ALDEBARAN	ALDEBAN	1.1	291 50	N. 16 24	Aldebaran
4	ALPHERATZ	ALPHAZ	2.2	358 38	N. 28 47	Alpheratz
5	ALTAIR	ALTAIR	0.9	62 59	N. 8 43	Altair
6	ANTARES	ANTARES	1.2	113 31	S. 26 18	Antares
7	ARCTURUS	ARCTUS	0.2	146 43	N. 19 28	Arcturus
8	BETELGEUSE	BETELUS	0.5-1.1	271 58	N. 7 24	Betelgeux
9	CANOPUS	CANOPUS	-0.9	264 19	S. 52 40	Canopus
10	CAPELLA	CAPELLA	0.2	281 52	N. 45 57	Capella
11	DENEK	DENEK	1.3	50 07	N. 45 05	Deneb
12	DUBHE	DUBHE	2.0	194 56	N. 62 03	Dubhe
13	FOMALHAUT	FOMALT	1.3	16 22	S. 29 55	Fomalhaut
14	PEACOCK	PEACOCK	2.1	54 42	S. 56 55	Peacock
15	POLLUX	POLLUX	1.2	244 32	N. 28 10	Pollux
16	PROCYON	PROCYON	0.5	245 54	N. 5 22	Procyon
17	REGULUS	REGULUS	1.3	208 39	N. 12 14	Regulus
18	RIGEL	RIGEL	0.3	282 02	S. 8 16	Rigel
19	RIGEL KENT.	RIGENT	0.1	141 03	S. 60 36	Rigel Kent.
20	SIRIUS	SIRIUS	-1.6	259 20	S. 16 38	Sirius
21	SPICA	SPICA	1.2	159 26	S. 10 52	Spica
22	VEGA	VEGA	0.1	81 15	N. 38 44	Vega

LIST II.—Supplementary Stars for use with A.N. Tables, though less simply than with List I; not used with the Astrograph.

23	Adara	...	1.6	255 54	S. 28 54	Adhara
24	Alhena	...	1.9	261 23	N. 16 27	γ Gem.
25	Alnitak	...	1.9	275 31	S. 1 58	ζ Orionis
26	Alphacca	...	2.3	126 55	N. 26 54	Alphecca
27	Alphard	...	2.2	218 47	S. 8 25	Alphard
28	Anilam	...	1.8	276 40	S. 1 14	Alnilam
29	Bellatrix	...	1.7	279 28	N. 6 18	Bellatrix
30	Denebola	...	2.2	183 27	N. 14 53	Denebola
31	Diphda	...	2.2	349 49	S. 18 18	Deneb Kait.
32	Hamal	...	2.2	329 00	N. 23 12	Hamal
33	Nath	...	1.8	279 19	N. 28 34	El Nath
34	Ras Alhague	...	2.1	96 55	N. 12 36	Rasalague
35	Wezen	...	2.0	253 28	S. 26 18	δ Can. Maj.

LIST III.—Bright stars included for possible future use. At present only Nos. 39 (Astrograph) and 47 are used in Air Navigation.

36	Alioth	...	1.7	167 06	N. 56 16	Alioth
37	γ Argus	...	1.9	238 03	S. 47 10	γ Argus
38	Avior	...	1.7	234 39	S. 59 20	ε Argus
39	BENETNASCH	BENESH	1.9	153 40	N. 49 35	Alkaid
40	Castor	...	1.6	247 15	N. 32 01	Castor
41	β Centauri	...	0.9	150 02	S. 60 06	β Centauri
42	β Crucis	...	1.5	168 53	S. 59 23	β Crucis
43	γ Crucis	...	1.6	172 59	S. 56 48	γ Crucis
44	Kaus Aust.	...	2.0	84 53	S. 34 25	Kaus Aust.
45	Miaplacidus	...	1.8	221 51	S. 69 29	Miaplacidus
46	Mirfak	...	1.9	309 55	N. 49 40	Mirfak
47	POLARIS	...	2.1	333 48	N. 89 00	Polaris
48	Schedar	...	2.1-2.6	350 41	N. 56 14	Schedir
49	Shaula	...	1.7	97 33	S. 37 04	Shaula
50	α Tri. Aust.	...	1.9	109 19	S. 68 55	α Tri. Aust.

INTERPOLATION OF
G.H.A. ARIES (γ) AND
G.H.A. PLANETS

Increment to be added to G.H.A. of
Aries and Planets for intervals of G.M.T.

00 00	00 00	03 17	05 50	06 36	1 40
01 01	01 01	21 01	05 51	40 14	1 41
05 02	05 02	25 02	05 52	44 14	1 42
09 03	09 03	29 03	05 53	48 14	1 43
13 04	13 04	33 04	05 54	52 14	1 44
17 05	17 05	37 05	05 55	06 56	1 45
21 06	21 06	41 06	05 56	07 00	1 46
25 07	25 07	45 07	05 57	04 17	1 47
29 08	29 08	49 08	05 58	08 18	1 48
33 09	33 09	53 09	05 59	12 19	1 49
37 10	37 10	03 57	1 00	16 15	1 50
41 01	41 01	04 01	1 01	20 15	1 51
45 02	45 02	05 02	1 02	24 15	1 52
49 03	49 03	09 03	1 03	28 15	1 53
53 04	53 04	13 04	1 04	32 15	1 54
00 57	00 57	17 05	1 05	36 15	1 55
01 01	01 01	21 06	1 06	40 15	1 56
05 07	05 07	25 07	1 07	44 15	1 57
09 08	09 08	29 08	1 08	48 15	1 58
13 09	13 09	33 09	1 09	52 15	1 59
17 10	17 10	37 10	1 10	07 56	2 00
21 11	21 11	41 11	1 11	08 00	2 01
25 12	25 12	45 12	1 12	04 02	2 02
29 13	29 13	49 13	1 13	08 03	2 03
33 14	33 14	53 14	1 14	12 04	2 04
37 15	37 15	04 57	1 15	16 05	2 05
41 16	41 16	05 01	1 16	20 06	2 06
45 17	45 17	05 17	1 17	24 07	2 07
49 18	49 18	09 18	1 18	28 08	2 08
53 19	53 19	13 19	1 19	32 09	2 09
01 57	01 57	17 20	1 20	36 10	2 10
02 01	02 01	21 21	1 21	40 11	2 11
05 32	05 32	25 22	1 22	44 12	2 12
09 33	09 33	29 23	1 23	48 13	2 13
13 34	13 34	33 24	1 24	52 14	2 14
17 35	17 35	37 25	1 25	08 56	2 15
21 36	21 36	41 26	1 26	09 00	2 16
25 37	25 37	45 27	1 27	04 17	2 17
29 38	29 38	49 28	1 28	08 18	2 18
33 39	33 39	53 29	1 29	12 19	2 19
37 40	37 40	05 57	1 30	16 20	2 20
41 41	41 41	06 01	1 31	20 21	2 21
45 42	45 42	05 05	1 32	24 22	2 22
49 43	49 43	08 08	1 33	28 23	2 23
53 44	53 44	12 12	1 34	32 24	2 24
02 57	02 57	16 16	1 35	36 25	2 25
03 01	03 01	20 20	1 36	40 26	2 26
05 47	05 47	24 24	1 37	44 27	2 27
09 48	09 48	28 28	1 38	48 28	2 28
13 49	13 49	32 32	1 39	52 29	2 29
17 50	17 50	36 36	1 40	09 56	2 30
03 21	03 21	06 40		10 00	

When the argument is an exact tabulated value the upper of the two possible values of the result should be taken.

SUN AND MOON — SATURDAY, 1 APRIL 1944 (GREENWICH DATE)

S.D. 16'							SUN		Mer. Pass. 12 ^h 04 ^m		Lat.	Twilight	Sun-rise	Sun-set	Twilight	Moon's P. in A.	Lat.	Moon-rise	Diff.
G. M. T.	G.H.A.						Dec.	N. 72	h m	h m	h m	h m	h m	Alt.	Corr.	N. 72	M.A.H.	m	
	00 ^m	10 ^m	20 ^m	30 ^m	40 ^m	50 ^m		71	03 51	05 01	19 09	20 17	0	+	71	M.A.H.	...		
								70	03 59	05 04	19 06	20 10	0	+	70	M.A.H.	...		
00	178 59	181 29	183 59	186 29	188 59	191 29	N. 4 25	N. 68	04 11	05 10	19 00	19 57	5 55	5 55	N. 68	08 18	36		
01	193 59	196 29	198 59	201 29	203 59	206 29	4 26	66	04 22	05 15	18 55	19 46	12 54	12 54	66	09 02	32		
02	208 59	211 29	213 59	216 29	218 59	221 29	4 27	64	04 30	05 19	18 51	19 38	16 53	16 53	64	09 32	31		
03	223 59	226 29	229 00	231 30	234 00	236 30	4 28	62	04 37	05 23	18 47	19 31	19 52	19 52	62	09 55	30		
04	239 00	241 30	244 00	246 30	249 00	251 30	4 29	60	04 44	05 26	18 43	19 24	22 51	22 51	60	10 13	29		
05	254 00	256 30	259 00	261 30	264 00	266 30	N. 4 30	N. 58	04 49	05 29	18 40	19 19	25 50	25 50	N. 58	10 28	29		
06	269 00	271 30	274 00	276 30	279 00	281 30	4 31	56	04 53	05 32	18 38	19 15	27 49	27 49	56	10 41	28		
07	284 00	286 30	289 00	291 30	294 00	296 30	4 32	54	04 58	05 34	18 35	19 10	29 48	29 48	54	10 52	28		
08	299 00	301 30	304 00	306 30	309 00	311 31	4 33	52	05 01	05 36	18 33	19 07	31 47	31 47	52	11 02	28		
09	314 01	316 31	319 01	321 31	324 01	326 31	4 34	50	05 05	05 38	18 31	19 03	33 46	33 46	50	11 11	27		
10	329 01	331 31	334 01	336 31	339 01	341 31	N. 4 35	N. 45	05 12	05 42	18 27	18 56	35 45	35 45	N. 45	11 29	27		
11	344 01	346 31	349 01	351 31	354 01	356 31	4 36	40	05 17	05 45	18 24	18 51	37 44	37 44	40	11 44	27		
12	359 01	1 31	4 01	6 31	9 01	11 31	4 37	35	05 22	05 48	18 21	18 46	39 43	39 43	35	11 58	26		
13	14 01	16 31	19 01	21 31	24 01	26 31	4 38	30	05 26	05 50	18 19	18 42	40 42	40 42	30	12 09	26		
14	29 02	31 32	34 02	36 32	39 02	41 32	4 39	20	05 32	05 54	18 14	18 36	42 41	42 41	20	12 28	25		
15	44 02	46 32	49 02	51 32	54 02	56 32	N. 4 40	N. 10	05 36	05 58	18 11	18 32	43 39	43 39	N. 10	12 44	25		
16	59 02	61 32	64 02	66 32	69 02	71 32	4 41	0	05 40	06 01	18 07	18 28	45 38	45 38	0	13 00	24		
17	74 02	76 32	79 02	81 32	84 02	86 32	4 41	S. 10	05 43	06 04	18 04	18 25	46 36	46 36	S. 10	13 16	24		
18	89 02	91 32	94 02	96 32	99 02	101 32	4 42	20	05 45	06 08	18 01	18 23	48 37	48 37	20	13 33	23		
19	104 02	106 32	109 03	111 33	114 03	116 33	4 43	30	05 47	06 11	17 57	18 21	49 35	49 35	30	13 51	23		
20	119 03	121 33	124 03	126 33	129 03	131 33	N. 4 44	S. 35	05 48	06 13	17 55	18 20	50 34	50 34	S. 35	14 03	23		
21	134 03	136 33	139 03	141 33	144 03	146 33	4 45	40	05 48	06 16	17 53	18 19	52 33	52 33	40	14 16	22		
22	149 03	151 33	154 03	156 33	159 03	161 33	4 46	45	05 49	06 18	17 50	18 19	53 32	53 32	45	14 31	22		
23	164 03	166 33	169 03	171 33	174 03	176 33	4 47	S. 50	05 49	06 22	17 47	18 19	54 31	54 31	S. 50	14 49	21		

S.D. 15'							MOON		Age 8 ^d 0		Mer. Pass. 19 ^h 12 ^m		Diff. 24 ^m		Lat.	Moon-set	Diff.	
G. M. T.	00 ^m		10 ^m		20 ^m		30 ^m	40 ^m	50 ^m									
	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.				
00	81 32	N. 20 52	83 57	N. 20 52	86 22	N. 20 52	88 47	N. 20 52	91 12	N. 20 51	93 37	N. 20 51	27 27	27 27	N. 72	M.A.H.	...	
01	96 02	20 51	98 27	20 51	100 52	20 51	103 17	20 50	105 42	20 50	108 07	20 50	27 26	27 26	71	M.A.H.	...	
02	110 32	20 50	112 57	20 49	115 22	20 49	117 47	20 49	120 12	20 49	122 37	20 48	27 25	27 25	70	M.A.H.	...	
03	125 02	20 48	127 27	20 48	129 52	20 48	132 17	20 48	134 42	20 47	137 07	20 47	27 24	27 24	63	N. 68	05 20	
04	139 32	20 47	141 57	20 47	144 22	20 46	146 47	20 46	149 12	20 46	151 37	20 45	27 23	27 23	64	24	N. 68	
05	154 02	N. 20 45	156 27	N. 20 45	158 52	N. 20 45	161 17	N. 20 44	163 42	N. 20 44	166 07	N. 20 44	27 22	27 22	65	23	66	
06	168 32	20 44	170 57	20 43	173 22	20 43	175 47	20 43	178 12	20 42	180 37	20 42	27 21	27 21	66	22	64	
07	183 02	20 42	185 27	20 41	187 52	20 41	190 17	20 41	192 42	20 40	195 07	20 40	27 20	27 20	66	21	62	
08	197 32	20 40	199 57	20 40	202 22	20 39	204 47	20 39	207 12	20 39	209 37	20 38	27 19	27 19	68	20	60	
09	212 02	20 38	214 27	20 38	216 52	20 37	219 17	20 37	221 42	20 37	224 07	20 36	27 18	27 18	69	19	N. 58	
10	226 32	N. 20 36	228 57	N. 20 35	231 22	N. 20 35	233 47	N. 20 35	236 12	N. 20 34	238 37	N. 20 34	27 17	27 17	70	18	56	
11	241 02	20 34	243 27	20 33	245 53	20 33	248 18	20 32	250 43	20 32	253 08	20 32	27 16	27 16	71	17	54	
12	255 33	20 31	257 58	20 31	260 23	20 31	262 48	20 30	265 13	20 30	267 38	20 29	27 15	27 15	72	16	52	
13	270 03	20 29	272 28	20 29	274 53	20 28	277 18	20 28	279 43	20 27	282 08	20 27	27 14	27 14	73	15	50	
14	284 33	20 26	286 58	20 26	289 23	20 26	291 49	20 25	294 14	20 25	296 39	20 24	27 13	27 13	74	14	N. 45	
15	299 04	N. 20 24	301 29	N. 20 23	303 54	N. 20 23	306 19	N. 20 23	308 44	N. 20 22	311 09	N. 20 22	27 12	27 12	75	13	40	
16	313 34	20 21	315 59	20 21	318 24	20 20	320 49	20 20	323 14	20 19	325 39	20 19	27 11	27 11	76	12	35	
17	328 05	20 18	330 30	20 18	332 55	20 18	335 20	20 17	337 45	20 17	340 10	20 16	27 10	27 10	77	11	30	
18	342 35	20 16	345 00	20 15	347 25	20 15	349 50	20 14	352 15	20 14	354 41	20 13	27 09	27 09	78	10	20	
19	357 06	20 13	359 31	20 12	1 56	20 12	4 21	20 11	6 46	20 11	9 11	20 10	27 08	27 08	80	10	N. 10	
20	11 36	N. 20 10	14 01	N. 20 09	16 26	N. 20 09	18 51	N. 20 08	21 17	N. 20 08	23 42	N. 20 07	27 07	27 07	0	00 51	25	
21	26 07	20 06	28 32	20 06	30 57	20 05	33 22	20 05	35 47	20 04	38 12	20 04	27 06	27 06	0	00 35	25	
22	40 37	20 03	43 03	20 03	45 28	20 02	47 53	20 02	50 18	20 01	52 43	20 00	27 05	27 05	0	00 19	25	
23	55 08	20 00	57 33	19 59	59 58	19 59	62 24	19 58	64 49	19 58	67 14	19 57	27 04	27 04	0	00 02	25	

To be added to observed altitude of the Moon.	0	30	(23 42)	26
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ARIES (♈) AND PLANETS—SATURDAY, 1 APRIL 1944 (GREENWICH DATE)

ARIES (♈)							VENUS							Mer. Pass. 10 ^h 43 ^m	
							Mag. -3.3								
							Morning star, about 25° north-north-east of Fomalhaut.								
G. M. T.	G.H.A.						G. M. T.	Mean S.H.A. 10°		G.H.A.		360°-S.H.A. 350°		Dec.	
	00 ^m	10 ^m	20 ^m	30 ^m	40 ^m	50 ^m		00 ^m	10 ^m	20 ^m	30 ^m	40 ^m	50 ^m		
^h							^h								
00	189 14	191 44	194 14	196 45	199 15	201 46	00	199 26	201 56	204 26	206 55	209 25	211 55	S.5 54	
01	204 16	206 46	209 17	211 47	214 18	216 48	01	214 25	216 55	219 25	221 55	224 25	226 55	5 53	
02	219 19	221 49	224 19	226 50	229 20	231 51	02	229 25	231 55	234 25	236 55	239 25	241 55	5 51	
03	234 21	236 51	239 22	241 52	244 23	246 53	03	244 24	246 54	249 24	251 54	254 24	256 54	5 50	
04	249 23	251 54	254 24	256 55	259 25	261 56	04	259 24	261 54	264 24	266 54	269 24	271 54	5 49	
05	264 26	266 56	269 27	271 57	274 28	276 58	05	274 24	276 54	279 24	281 54	284 23	286 53	S.5 48	
06	279 28	281 59	284 29	287 00	289 30	292 00	06	289 23	291 53	294 23	296 53	299 23	301 53	5 47	
07	294 31	297 01	299 32	302 02	304 32	307 03	07	304 23	306 53	309 23	311 53	314 23	316 53	5 46	
08	309 33	312 04	314 34	317 05	319 35	322 05	08	319 23	321 52	324 22	326 52	329 22	331 52	5 44	
09	324 36	327 06	329 37	332 07	334 37	337 08	09	334 22	336 52	339 22	341 52	344 22	346 52	5 43	
10	339 38	342 09	344 39	347 09	349 40	352 10	10	349 22	351 52	354 22	356 52	359 21	1 51	S.5 42	
11	354 41	357 11	359 42	2 12	4 42	7 13	11	4 21	6 51	9 21	11 51	14 21	16 51	5 41	
12	9 43	12 14	14 44	17 14	19 45	22 15	12	19 21	21 51	24 21	26 51	29 21	31 51	5 40	
13	24 46	27 16	29 46	32 17	34 47	37 18	13	34 21	36 50	39 20	41 50	44 20	46 50	5 39	
14	39 48	42 19	44 49	47 19	49 50	52 20	14	49 20	51 50	54 20	56 50	59 20	61 50	5 37	
15	54 51	57 21	59 51	62 22	64 52	67 23	15	64 20	66 50	69 20	71 50	74 20	76 49	S.5 36	
16	69 53	72 23	74 54	77 24	79 55	82 25	16	79 19	81 49	84 19	86 49	89 19	91 49	5 35	
17	84 55	87 26	89 56	92 27	94 57	97 28	17	94 19	96 49	99 19	101 49	104 19	106 49	5 34	
18	99 58	102 28	104 59	107 29	110 00	112 30	18	109 19	111 49	114 18	116 48	119 18	121 48	5 33	
19	115 00	117 31	120 01	122 32	125 02	127 32	19	124 18	126 48	129 18	131 48	134 18	136 48	5 32	
20	130 03	132 33	135 04	137 34	140 05	142 35	20	139 18	141 48	144 18	146 48	149 18	151 47	S.5 30	
21	145 05	147 36	150 06	152 37	155 07	157 37	21	154 17	156 47	159 17	161 47	164 17	166 47	5 29	
22	160 08	162 38	165 09	167 39	170 09	172 40	22	169 17	171 47	174 17	176 47	179 17	181 47	5 28	
23	175 10	177 41	180 11	182 42	185 12	187 42	23	184 17	186 47	189 16	191 46	194 16	196 46	5 27	

Mag. -1.9 JUPITER Mer. Pass. 2^h 40^m
Conspicuous evening star, about 10° west of Regulus.

G. M. T.	Mean S.H.A. 220°		G.H.A.		360°-S.H.A. 140°		Dec.
	00 ^m	10 ^m	20 ^m	30 ^m	40 ^m	50 ^m	
00	49 11	51 41	54 11	56 42	59 12	61 43	N.16 41
01	64 13	66 44	69 14	71 44	74 15	76 45	16 41
02	79 16	81 46	84 17	86 47	89 17	91 48	16 41
03	94 18	96 49	99 19	101 49	104 20	106 50	16 41
04	109 21	111 51	114 22	116 52	119 22	121 53	16 41
05	124 23	126 54	129 24	131 55	134 25	136 55	N.16 41
06	139 26	141 56	144 27	146 57	149 28	151 58	16 41
07	154 28	156 59	159 29	162 00	164 30	167 01	16 41
08	169 31	172 01	174 32	177 02	179 33	182 03	16 41
09	184 34	187 04	189 34	192 05	194 35	197 06	16 41
10	199 36	202 07	204 37	207 07	209 38	212 08	N.16 41
11	214 39	217 09	219 40	222 10	224 40	227 11	16 41
12	229 41	232 12	234 42	237 12	239 43	242 13	16 41
13	244 44	247 14	249 45	252 15	254 45	257 16	16 41
14	259 46	262 17	264 47	267 18	269 48	272 18	16 41
15	274 49	277 19	279 50	282 20	284 51	287 21	N.16 41
16	289 51	292 22	294 52	297 23	299 53	302 24	16 42
17	304 54	307 24	309 55	312 25	314 56	317 26	16 42
18	319 57	322 27	324 57	327 28	329 58	332 29	16 42
19	334 59	337 30	340 00	342 30	345 01	347 31	16 42
20	350 02	352 32	355 03	357 33	0 03	2 34	N.16 42
21	5 04	7 35	10 05	12 35	15 06	17 36	16 42
22	20 07	22 37	25 08	27 38	30 08	32 39	16 42
23	35 09	37 40	40 10	42 41	45 11	47 41	16 42

Mag. 0.3 SATURN Mer. Pass. 16^h 42^m
Evening star, north of Betelgeuse and north-east of Aldebaran.

G. M. T.	Mean S.H.A. 280°		G.H.A.		360°-S.H.A. 80°		Dec.
	00 ^m	10 ^m	20 ^m	30 ^m	40 ^m	50 ^m	
00	108 46	111 17	113 47	116 17	118 48	121 18	N.22 06
01	123 48	126 19	128 49	131 20	133 50	136 20	22 06
02	138 51	141 21	143 51	146 22	148 52	151 23	22 06
03	153 53	156 23	158 54	161 24	163 54	166 25	22 06
04	168 55	171 26	173 56	176 26	178 57	181 27	22 06
05	183 57	186 28	188 58	191 29	193 59	196 29	N.22 06
06	199 00	201 30	204 01	206 31	209 01	211 32	22 06
07	214 02	216 32	219 03	221 33	224 04	226 34	22 06
08	229 04	231 35	234 05	236 35	239 06	241 36	22 06
09	244 07	246 37	249 07	251 38	254 08	256 38	22 06
10	259 09	261 39	264 10	266 40	269 10	271 41	N.22 06
11	274 11	276 42	279 12	281 42	284 13	286 43	22 06
12	289 13	291 44	294 14	296 45	299 15	301 45	22 06
13	304 16	306 46	309 16	311 47	314 17	316 48	22 06
14	319 18	321 48	324 19	326 49	329 19	331 50	22 06
15	334 20	336 51	339 21	341 51	344 22	346 52	N.22 06
16	349 23	351 53	354 23	356 54	359 24	1 54	22 06
17	4 25	6 55	9 26	11 56	14 26	16 57	22 06
18	19 27	21 57	24 28	26 58	29 29	31 59	22 06
19	34 29	37 00	39 30	42 00	44 31	47 01	22 06
20	49 32	52 02	54 32	57 03	59 33	62 04	N.22 06
21	64 34	67 04	69 35	72 05	74 35	77 06	22 06
22	79 36	82 07	84 37	87 07	89 38	92 08	22 06
23	94 38	97 09	99 39	102 10	104 40	107 10	22 06

POLARIS (POLE STAR) TABLE, 1944

FOR DETERMINING THE LATITUDE FROM AN OBSERVED ALTITUDE

L.H.A. γ Q	L.H.A. γ Q	L.H.A. γ Q	L.H.A. γ Q	L.H.A. γ Q	L.H.A. γ Q	L.H.A. γ Q
359 37	84 14	119 10	155 51	245 50	285 46	319 50
1 48 -55	85 21 -32	120 08 + 3	157 07 +38	247 20 +45	286 44 +10	320 53 -25
4 11 -56	86 27 -31	121 05 + 4	158 24 +39	248 47 +44	287 43 + 9	321 55 -26
6 49 -57	87 32 -30	122 03 + 5	159 43 +40	250 12 +43	288 41 + 8	322 59 -27
9 52 -58	88 36 -29	123 01 + 6	161 04 +41	251 35 +42	289 38 + 7	324 03 -28
13 36 -59	89 40 -28	123 58 + 7	162 27 +42	252 56 +41	290 36 + 6	325 07 -29
18 59 -60	90 44 -27	124 56 + 8	163 52 +43	254 15 +40	291 34 + 5	326 12 -30
33 40 -61	91 46 -26	125 55 + 9	165 19 +44	255 32 +39	292 31 + 4	327 18 -31
39 03 -60	92 49 -25	126 53 +10	166 49 +45	256 48 +38	293 29 + 3	328 25 -32
42 47 -59	93 50 -24	127 52 +11	168 21 +46	258 02 +37	294 26 + 2	329 32 -33
45 50 -58	94 52 -23	128 50 +12	169 58 +47	259 15 +36	295 24 + 1	330 41 -34
48 28 -57	95 53 -22	129 49 +13	171 38 +48	260 27 +35	296 21 + 0	331 50 -35
50 51 -56	96 53 -21	130 49 +14	173 22 +49	261 38 +34	297 18 - 1	333 00 -36
53 02 -55	97 54 -20	131 48 +15	175 12 +50	262 48 +33	298 15 - 2	334 11 -37
55 03 -54	98 53 -19	132 48 +16	177 07 +51	263 57 +32	299 13 - 3	335 24 -38
56 56 -53	99 53 -18	133 48 +17	179 11 +52	265 05 +31	300 10 - 4	336 37 -39
58 44 -52	100 52 -17	134 49 +18	181 23 +53	266 12 +30	301 07 - 5	337 52 -40
60 27 -51	101 51 -16	135 50 +19	183 48 +54	267 19 +29	302 05 - 6	339 09 -41
62 06 -50	102 50 -15	136 51 +20	186 30 +55	268 25 +28	303 02 - 7	340 27 -42
63 40 -49	103 49 -14	137 53 +21	189 35 +56	269 30 +27	304 00 - 8	341 46 -43
65 12 -48	104 47 -13	138 55 +22	193 22 +57	270 34 +26	304 58 - 9	343 08 -44
66 41 -47	105 45 -12	139 58 +23	198 52 +58	271 38 +25	305 56 -10	344 32 -45
68 07 -46	106 43 -11	141 01 +24	203 47 +59	272 41 +24	306 54 -11	345 58 -46
69 31 -45	107 41 -10	142 05 +25	209 17 +58	273 44 +23	307 52 -12	347 27 -47
70 53 -44	108 39 - 9	143 09 +26	213 04 +57	274 46 +22	308 50 -13	348 59 -48
72 12 -43	109 37 - 8	144 14 +27	219 17 +56	275 48 +21	309 49 -14	350 33 -49
73 30 -42	110 34 - 7	145 20 +28	226 09 +55	276 49 +20	310 48 -15	352 12 -50
74 47 -41	111 32 - 6	146 27 +29	231 16 +54	277 50 +19	311 47 -16	353 55 -51
76 02 -40	112 29 - 5	147 34 +30	233 28 +53	278 51 +18	312 46 -17	355 43 -52
77 15 -39	113 26 - 4	148 42 +31	235 32 +52	279 51 +17	313 46 -18	357 36 -53
78 28 -38	114 24 - 3	149 51 +32	237 27 +51	280 51 +16	314 45 -19	359 37 -54
79 39 -37	115 21 - 2	151 01 +33	239 17 +50	281 50 +15	315 46 -20	1 48 -55
80 49 -36	116 18 - 1	152 12 +34	241 01 +49	282 50 +14	316 46 -21	4 11 -56
81 58 -35	117 15 - 0	153 24 +35	242 41 +48	283 49 +13	317 47 -22	6 49 -57
83 07 -34	118 13 + 1	154 37 +36	244 18 +47	284 47 +12	318 49 -23	9 52 -58
84 14 -33	119 10 + 2	155 51 +37	245 50 +46	285 46 +11	319 50 -24	13 36 -59

When the argument is an exact tabulated value, the *upper* of the two possible values of the result should be taken.

The above table, which includes refraction, gives the quantity Q , with its sign, to be applied to the observed altitude (corrected for dip if necessary) of *Polaris* to obtain the latitude of the observer.

The table alongside gives an additional correction to be applied to the observed altitude of *Polaris* when special accuracy is required. This additional correction will normally be neglected (except at low heights in low latitudes) unless accurate observations are available.

ADJUSTMENT TO POLARIS TABLE

Height in Feet	Observed Altitude						
	10°	15°	20°	30°	45°	60°	75°
0	-5	-3	-2	-1	0	+1	+1
5,000	-4	-2	-1	-1	0	+1	+1
10,000	-3	-2	-1	0	0	+1	+2
15,000	-3	-1	-1	0	0	+1	+2
20,000	-2	-1	-1	0	0	+1	+2
25,000	-2	-1	0	0	+1	+1	+2
30,000	-1	-1	0	0	+1	+1	+2
35,000	-1	0	0	0	+1	+1	+2
40,000	0	0	0	0	+1	+1	+2

INTERPOLATION OF G.H.A. SUN

Increment to be added to G.H.A. of Sun for intervals of G.M.T.

m s	m s	m s	m s	m s	m s
00 00 °	01 37 °	03 17 °	04 57 °	06 37 °	08 17 °
01 00 °	41 ° 25	21 ° 50	05 01 ° 15	41 ° 40	21 ° 05
05 00 °	45 ° 27	25 ° 52	05 17 ° 16	45 ° 41	25 ° 06
09 00 °	49 ° 28	29 ° 53	09 17 ° 18	49 ° 42	29 ° 07
13 00 °	53 ° 29	33 ° 54	13 17 ° 19	53 ° 43	33 ° 08
17 00 °	01 57 ° 30	37 ° 55	17 17 ° 20	57 ° 44	37 ° 09
21 00 °	02 01 ° 31	41 ° 56	21 17 ° 21	01 ° 45	41 ° 10
25 00 °	05 ° 32	45 ° 57	25 17 ° 22	05 ° 46	45 ° 11
29 00 °	09 ° 33	49 ° 58	29 17 ° 23	09 ° 47	49 ° 12
33 00 °	13 ° 34	53 ° 59	33 17 ° 24	13 ° 48	53 ° 13
37 00 °	17 ° 35	03 57 ° 00	37 17 ° 25	17 ° 49	57 ° 14
41 00 °	21 ° 36	04 01 ° 01	41 17 ° 26	21 ° 50	01 ° 15
45 00 °	25 ° 37	05 ° 02	45 17 ° 27	25 ° 51	05 ° 16
49 00 °	29 ° 38	09 ° 03	49 17 ° 28	29 ° 52	09 ° 17
53 00 °	33 ° 39	13 ° 04	53 17 ° 29	33 ° 53	13 ° 18
00 57 ° 15	37 ° 40	17 ° 05	05 57 ° 30	37 ° 54	17 ° 19
01 01 ° 16	41 ° 41	21 ° 06	06 01 ° 31	41 ° 55	21 ° 20
05 01 ° 17	45 ° 42	25 ° 07	05 13 ° 32	45 ° 56	25 ° 21
09 01 ° 18	49 ° 43	29 ° 08	09 13 ° 33	49 ° 57	29 ° 22
13 01 ° 19	53 ° 44	33 ° 09	13 13 ° 34	53 ° 58	33 ° 23
17 01 ° 20	02 57 ° 45	37 ° 10	17 13 ° 35	57 ° 59	37 ° 24
21 01 ° 21	03 01 ° 46	41 ° 11	21 13 ° 36	01 ° 00	41 ° 25
25 01 ° 22	05 ° 47	45 ° 12	25 13 ° 37	05 ° 01	45 ° 26
29 01 ° 23	09 ° 48	49 ° 13	29 13 ° 38	09 ° 02	49 ° 27
33 01 ° 24	13 ° 49	53 ° 14	33 13 ° 39	13 ° 03	53 ° 28
37 01 ° 25	17 ° 50	04 57 ° 15	37 13 ° 40	17 ° 04	57 ° 29
01 41 °	03 21 °	05 01 °	06 41 °	21 ° 05	09 57 ° 30

INTERPOLATION OF MOONRISE, ETC. FOR LONGITUDE

Add if longitude west.
Subtract if longitude east.

Longi- tude	Diff.					
	5	10	15	20	25	30
0 °	00	00	00	00	00	00
20 °	01	01	02	02	03	03
40 °	01	02	03	04	06	07
60 °	02	03	05	07	08	10
80 °	02	04	07	09	11	13
100 °	03	06	08	11	14	17
120 °	03	07	10	13	17	20
140 °	04	08	12	16	19	23
160 °	04	09	13	18	22	27
180 °	05	10	15	20	25	30

Longi- tude	Diff.					
	35	40	45	50	55	60
0 °	00	00	00	00	00	00
15 °	03	03	04	04	05	05
30 °	06	07	08	08	09	10
45 °	09	10	11	12	14	15
60 °	12	13	15	17	18	20
75 °	15	17	19	21	23	25
90 °	18	20	22	25	28	30
105 °	20	23	26	29	32	35
120 °	23	27	30	33	37	40
135 °	26	30	34	38	41	45
150 °	29	33	38	42	46	50
165 °	32	37	41	46	50	55
180 °	35	40	45	50	55	60

Longi- tude	Diff.					
	65	70	75	80	85	90
0 °	00	00	00	00	00	00
10 °	04	04	04	04	05	05
20 °	07	08	08	09	09	10
30 °	11	12	12	13	14	15
40 °	14	16	17	18	19	20
50 °	18	19	21	22	24	25
60 °	22	23	25	27	28	30
70 °	25	27	29	31	33	35
80 °	29	31	33	36	38	40
90 °	32	35	38	40	42	45
100 °	36	39	42	44	47	50
110 °	40	43	46	49	52	55
120 °	43	47	50	53	57	60
130 °	47	51	54	58	61	65
140 °	51	54	58	62	66	70
150 °	54	58	62	67	71	75
160 °	58	62	67	71	76	80
170 °	61	66	71	76	80	85
180 °	65	70	75	80	85	90

Note:—When the *Diffs.* are negative *subtract* correction if longitude *west*. Add correction if longitude *east*.

MOON

Increment to be added to G.H.A. of Moon for intervals of G.M.T.

m s	m s	m s	m s	m s	m s
00 00 °	01 37 °	03 16 °	04 56 °	06 35 °	08 18 °
02 00 °	41 ° 24	20 ° 48	05 00 ° 12	39 ° 36	23 ° 01
06 00 °	45 ° 26	24 ° 49	05 13 ° 13	43 ° 37	27 ° 02
10 00 °	49 ° 27	29 ° 51	05 27 ° 14	47 ° 38	31 ° 03
14 00 °	53 ° 28	33 ° 52	05 41 ° 15	51 ° 39	35 ° 04
18 00 °	01 57 ° 29	37 ° 53	05 55 ° 16	55 ° 40	39 ° 05
22 00 °	02 02 ° 30	41 ° 54	06 09 ° 17	59 ° 41	43 ° 06
26 00 °	06 ° 31	45 ° 55	06 23 ° 18	03 ° 42	47 ° 07
30 00 °	10 ° 32	49 ° 56	06 37 ° 19	07 ° 43	51 ° 08
34 00 °	14 ° 33	53 ° 57	06 51 ° 20	11 ° 44	55 ° 09
38 00 °	18 ° 34	57 ° 58	07 05 ° 21	15 ° 45	59 ° 10
42 00 °	22 ° 35	01 59	07 19 ° 22	19 ° 46	03 ° 11
46 00 °	26 ° 36	06 00	07 33 ° 23	23 ° 47	07 ° 12
50 00 °	31 ° 37	10 01	07 47 ° 24	27 ° 48	11 ° 13
00 55 ° 14	35 ° 38	14 02	08 01 ° 25	31 ° 49	15 ° 14
01 00 ° 15	39 ° 39	18 03	08 15 ° 26	35 ° 50	19 ° 15
04 00 ° 16	43 ° 40	22 04	08 29 ° 27	39 ° 51	23 ° 16
08 00 ° 17	47 ° 41	26 05	08 43 ° 28	43 ° 52	27 ° 17
12 00 ° 18	51 ° 42	30 06	08 57 ° 29	47 ° 53	31 ° 18
16 00 ° 19	55 ° 43	34 07	09 11 ° 30	51 ° 54	35 ° 19
20 00 ° 20	59 ° 44	38 08	09 25 ° 31	55 ° 55	39 ° 20
24 00 ° 21	03 ° 45	42 09	09 39 ° 32	59 ° 56	43 ° 21
28 00 ° 22	07 ° 46	46 10	09 53 ° 33	03 ° 57	47 ° 22
32 00 ° 23	11 ° 47	50 11	10 07 ° 34	07 ° 58	51 ° 23
36 00 ° 24	15 ° 48	54 12	10 21 ° 35	11 ° 59	55 ° 24
01 41 °	03 20 °	05 00 °	06 39 °	15 ° 00	09 58 ° 25

When the argument is an exact tabulated value, the *upper* of the two possible values of the result should be taken.

ASTROGRAPH, 1944 APRIL

EAST

EAST SETTING LONGITUDES

Local night and hours of A.M.T.											Corresponding G.M.T.
F./S. 31-1	S./S. 1-2	S./M. 2-3	M./Tu. 3-4	Tu./W. 4-5	W./Th. 5-6	Th./F. 6-7	F./S. 7-8	S./S. 8-9	S./M. 9-10	M./Tu. 10-11	
25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	
E ⁰ 18 13 50 21 21 36 23 51 26 66 28 81 31 96 33 111 36 126 38 141 41 156 43 171 46 ...	E ⁵ 19 12 51 20 22 35 24 50 27 65 29 80 32 95 34 110 37 125 39 140 41 155 44 170 46 ...	E ⁴ 20 11 51 19 23 34 25 49 28 64 30 79 32 94 35 109 37 124 40 139 42 154 45 169 47 ...	E ³ 21 10 52 18 23 33 26 48 28 63 31 78 33 93 36 108 38 123 41 138 43 153 46 168 48 ...	E ² 22 9 53 17 24 32 27 47 29 62 32 77 34 92 37 107 39 122 42 137 44 152 47 167 49 ...	E ¹ 23 8 54 16 25 31 28 46 30 61 33 76 35 91 38 106 40 121 42 136 45 151 47 166 50 ...	E ⁰ 24 7 55 15 26 30 29 45 31 60 33 75 36 90 38 105 41 120 43 135 46 150 48 165 51 ...	W ⁰ 36 E ⁶ 56 14 27 29 29 44 32 59 34 74 37 89 39 104 42 119 44 134 47 149 49 164 52 179 54	W ¹ 35 E ⁵ 57 13 28 28 30 43 33 58 35 73 38 88 40 103 43 118 45 133 47 148 50 163 52 178 55	W ² 34 E ⁴ 57 12 29 27 31 42 34 57 36 72 39 87 41 102 43 117 46 132 48 147 51 162 53 177 56	W ³ 33 E ³ 58 11 30 26 32 41 34 56 37 71 39 86 42 101 44 116 47 131 49 146 52 161 54 176 57	^h 24 23 30 23 22 21 20 19 18 17 16 15 14 13 12
Tu./W. 11-12	W./Th. 12-13	Th./F. 13-14	F./S. 14-15	S./S. 15-16	S./M. 16-17	M./Tu. 17-18	Tu./W. 18-19	W./Th. 19-20	Th./F. 20-21	F./S. 21-22	Corresponding G.M.T.
26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	
E ¹⁰ 30 18 02 25 33 40 35 55 38 70 40 85 43 100 45 115 48 130 50 145 53 160 55 175 57 ...	E ⁹ 31 17 02 24 34 39 36 54 39 69 41 84 44 99 46 114 48 129 51 144 53 159 56 174 58 ...	E ⁸ 32 16 03 23 34 38 37 53 39 68 42 83 44 98 47 113 49 128 52 143 54 158 57 173 59 ...	E ⁷ 33 15 04 22 35 37 38 52 40 67 43 82 45 97 48 112 50 127 53 142 55 157 58 172 01 ...	E ⁶ 34 14 05 21 36 36 39 51 41 66 44 81 46 96 49 111 51 126 54 141 56 156 59 171 02 ...	E ⁵ 35 13 06 20 37 35 40 50 42 65 45 80 47 95 49 110 52 125 54 140 57 155 59 170 03 ...	E ⁴ 36 12 07 19 38 34 40 49 43 64 45 79 48 94 50 109 53 124 55 139 58 154 01 169 04 ...	E ³ 36 11 08 18 39 33 41 48 44 63 46 78 49 93 51 108 54 123 56 138 59 153 02 168 04 ...	E ² 37 10 09 17 40 32 42 47 45 62 47 77 50 92 52 107 55 122 57 137 59 152 03 167 05 ...	E ¹ 38 9 09 16 41 31 43 46 46 61 48 76 50 91 53 106 55 121 58 136 01 151 04 166 06 ...	E ⁰ 39 8 10 15 41 30 44 45 46 60 49 75 51 90 54 105 56 120 59 135 01 150 04 165 06 ...	^h 24 23 30 23 22 21 20 19 18 17 16 15 14 13 12
S./S. 22-23	S./M. 23-24	M./Tu. 24-25	Tu./W. 25-26	W./Th. 26-27	Th./F. 27-28	F./S. 28-29	S./S. 29-30	S./M. 30-1	M./Tu. 1-2	Tu./W. 2-3	Corresponding G.M.T.
26 ^h	26 ^h	26 ^h	26 ^h	27 ^h	27 ^h	27 ^h	27 ^h	27 ^h	27 ^h	27 ^h	
W ⁰ 20 E ⁷ 11 14 42 29 45 44 47 59 50 74 52 89 55 104 57 120 00 135 02 150 04 165 07 ...	W ¹ 19 E ⁶ 12 13 43 28 46 43 48 58 51 73 53 88 56 103 58 119 00 134 03 149 05 164 08 179 10	W ² 18 E ⁵ 13 12 44 27 47 42 49 57 51 72 54 87 56 102 59 118 01 133 04 148 06 163 09 178 11	W ³ 18 E ⁴ 14 11 45 26 47 41 50 56 52 71 55 86 57 102 00 117 02 132 05 147 07 162 10 177 12	E ¹⁰ 46 18 17 25 48 40 51 55 53 70 56 85 58 101 01 116 03 131 05 146 08 161 10 176 13 ...	E ⁹ 47 17 18 24 49 39 52 54 54 69 56 84 59 100 01 115 04 130 06 145 09 160 11 175 14 ...	E ⁸ 47 16 19 23 50 38 52 53 55 68 57 84 00 99 02 114 05 129 07 144 10 159 12 174 15 ...	E ⁷ 48 15 20 22 51 37 53 52 56 67 58 83 01 98 03 113 06 128 08 143 11 158 13 173 15 ...	E ⁶ 49 14 20 21 52 36 54 51 57 66 59 82 02 97 04 112 06 127 09 142 11 157 14 172 16 ...	E ⁵ 50 13 21 20 53 35 55 50 57 66 00 81 02 96 05 111 07 126 10 141 12 156 15 171 17 ...	E ⁴ 51 12 22 19 53 34 56 49 58 65 01 80 03 95 06 110 08 125 11 140 13 155 16 170 18 ...	^h 24 23 30 23 22 21 20 19 18 17 16 15 14 13 12

On this page the corresponding G.M.T. is on the first (emphasised) of the two Greenwich Dates.

WEST

ASTROGRAPH, 1944 APRIL

WEST SETTING LONGITUDES

Local night and hours of A.M.T.											Corresponding G.M.T.
F./S. 31-1	S./S. 1-2	S./M. 2-3	M./Tu. 3-4	Tu./W. 4-5	W./Th. 5-6	Th./F. 6-7	F./S. 7-8	S./S. 8-9	S./M. 9-10	M./Tu. 10-11	
25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	25 ^h	
E6 18 W1 13 8 44 23 46 38 49 53 51 68 54 83 56 98 59 114 01 129 04 144 06 159 09 174 11	E5 19 W2 12 9 43 24 46 39 48 54 51 69 53 84 55 99 58 115 00 130 03 145 05 160 08 175 10	E4 20 W3 11 10 42 25 45 40 47 55 50 70 52 85 55 100 57 116 00 131 02 146 04 161 07 176 09	E3 21 W4 10 11 41 26 44 41 46 56 49 71 51 86 54 101 56 116 59 132 01 147 04 162 06 177 09	E2 22 W5 09 12 41 27 43 42 46 57 48 72 50 87 53 102 55 117 58 133 00 148 03 163 05 178 08	E1 23 W6 08 13 40 28 42 43 45 58 47 73 50 88 52 103 55 118 57 134 59 149 02 164 04 179 07	E0 24 W7 08 14 39 29 41 44 44 59 46 74 49 89 51 104 54 119 56 135 58 150 01 165 04 ...	W0 36 8 07 15 38 30 40 45 43 60 45 75 48 90 50 105 53 120 55 136 57 151 59 166 03 ...	W1 35 9 06 16 37 31 40 46 42 61 45 76 47 91 49 106 52 121 54 137 56 152 58 167 02 ...	W2 34 10 05 17 36 32 39 47 41 62 44 77 46 92 49 107 51 122 54 138 55 153 58 168 01 ...	W3 33 11 04 18 35 33 38 48 40 63 43 78 45 93 48 108 50 123 53 139 55 154 58 169 00 ...	00 00 30 01 02 03 04 05 06 07 08 09 10 11 12
Tu./W. 11-12	W./Th. 12-13	Th./F. 13-14	F./S. 14-15	S./S. 15-16	S./M. 16-17	M./Tu. 17-18	Tu./W. 18-19	W./Th. 19-20	Th./F. 20-21	F./S. 21-22	Corresponding G.M.T.
26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	26 ^h	
E10 30 E2 59 W4 32 19 35 34 37 49 39 64 42 79 44 94 47 109 49 124 52 139 54 154 57 169 59	E9 31 E2 00 W5 31 20 34 35 36 50 39 65 41 80 44 95 46 110 48 125 51 140 53 155 56 170 58	E8 32 E1 01 W6 30 21 33 36 35 51 38 66 40 81 43 96 45 111 48 126 50 141 52 156 55 171 57	E7 33 E0 02 W7 30 22 32 37 34 52 37 67 39 82 42 97 44 112 47 127 49 142 52 157 54 172 57	E6 34 W0 57 8 29 23 31 38 34 53 36 68 38 83 41 98 43 113 46 128 48 143 51 158 53 173 56	E5 35 W1 57 9 28 24 30 39 33 54 35 69 38 84 40 99 43 114 45 129 47 144 50 159 52 174 55	E4 36 W2 56 10 27 25 29 40 32 55 34 70 37 85 39 100 42 115 44 130 47 145 49 160 52 175 54	E3 36 W3 55 11 26 26 29 41 31 56 33 71 36 86 38 101 41 116 43 131 46 146 48 161 51 176 53	E2 37 W4 54 12 25 27 28 42 30 57 33 72 35 87 38 102 40 117 42 132 45 147 47 162 50 177 52	E1 38 W5 53 13 24 28 27 43 29 58 32 73 34 88 37 103 39 118 42 133 44 148 47 163 49 178 51	E0 39 W6 52 14 23 29 26 44 28 59 31 74 33 89 36 104 38 119 41 134 43 149 46 164 48 179 51	00 00 30 01 02 03 04 05 06 07 08 09 10 11 12
S./S. 22-23	S./M. 23-24	M./Tu. 24-25	Tu./W. 25-26	W./Th. 26-27	Th./F. 27-28	F./S. 28-29	S./S. 29-30	S./M. 30-1	M./Tu. 1-2	Tu./W. 2-3	Corresponding G.M.T.
26 ^h	26 ^h	26 ^h	26 ^h	27 ^h	27 ^h	27 ^h	27 ^h	27 ^h	27 ^h	27 ^h	
W0 20 7 51 15 23 30 25 45 28 60 30 75 32 90 35 105 37 120 40 135 42 150 45 165 47 ...	W1 19 8 51 16 22 31 24 46 27 61 29 76 32 91 34 106 37 121 39 136 41 151 44 166 46 ...	W2 18 9 50 17 21 32 23 47 26 62 28 77 31 92 33 107 36 122 38 137 41 152 43 167 46 ...	W3 18 10 49 18 20 33 22 48 25 63 27 78 30 93 32 108 35 123 37 138 40 153 42 168 45 ...	E10 46 E3 15 W4 17 19 19 34 22 49 24 64 27 79 29 94 31 109 34 124 36 139 39 154 41 169 44	E9 47 E2 15 W5 16 20 18 35 21 50 23 65 26 80 28 95 31 110 33 125 36 140 38 155 40 170 43	E8 47 E1 16 W6 15 21 17 36 20 51 22 66 25 81 27 96 30 111 32 126 35 141 37 156 40 171 42	E7 48 E0 17 W7 14 22 17 37 19 52 22 67 24 82 26 97 29 112 31 127 34 142 36 157 39 172 41	E6 49 W0 42 8 13 23 16 38 18 53 21 68 23 83 26 98 28 113 31 128 33 143 35 158 38 173 40	E5 50 W1 41 9 12 24 15 39 17 54 20 69 22 84 25 99 27 114 30 129 32 144 35 159 37 174 40	E4 51 W2 40 10 12 25 14 40 16 55 19 70 21 85 24 100 26 115 29 130 31 145 34 160 36 175 39	00 00 30 01 02 03 04 05 06 07 08 09 10 11 12

On this page the corresponding G.M.T. is on the second (emphasised) of the two Greenwich Dates.

CORRECTIONS TO BE APPLIED TO OBSERVED ALTITUDE

BUBBLE SEXTANT		MARINE SEXTANT	
A.N. TABLES ASTROGRAPH	OTHER TABLES	A.N. TABLES ASTROGRAPH	OTHER TABLES
Sextant Error Dome Refraction Adjustment for Refraction (Table A) Coriolis (as a shift of position line)	Sextant Error Dome Refraction Correction for Refraction (Table B) Coriolis (as a shift of position line)	Index Error Dome Refraction Adjustment for Refraction (Table A) Dip Semi-diameter (for Sun and Moon)	Index Error Dome Refraction Correction for Refraction (Table B) Dip Semi-diameter (for Sun and Moon)

For the Moon a correction for Parallax in Altitude must also be applied.

BUBBLE SEXTANT ERROR		STANDARD DOME REFRACTION	MARINE SEXTANT ERROR
Sextant No.		This refraction is to be subtracted when using sextant suspension in a perspex dome. (It must not be used if a calibration table is fitted to the dome, or if a flat glass plate is provided).	Sextant No.
Alt.	Corr.		Index Error
		Alt. Refn. Alt. Refn.	
		10 8 50 4	
		20 7 60 4	
		30 6 70 3	
		40 5 80 3	

TABLE A										TABLE B									
ADJUSTMENT FOR REFRACTION FOR A.N. TABLES AND ASTROGRAPH										CORRECTION FOR REFRACTION SUBTRACT FROM OBSERVED ALTITUDE									
Height in feet	Observed Altitude									Height in feet	Observed Altitude								
	4°	6°	8°	10°	15°	20°	30°	45°	60°		4°	6°	8°	10°	15°	20°	30°	45°	60°
0	-2	-1	-1	-1	0	0	0	0	0	0	-12	-8	-6	-5	-4	-3	-2	-1	-1
5000	0	0	0	0	0	0	0	0	0	5000	-10	-7	-6	-5	-3	-2	-1	-1	0
10000	+1	+1	+1	+1	0	0	0	0	0	10000	-9	-6	-5	-4	-3	-2	-1	-1	0
15000	2	2	2	1	+1	+1	0	0	0	15000	-8	-5	-4	-3	-2	-2	-1	-1	0
20000	3	2	2	2	1	1	+1	0	0	20000	-7	-5	-4	-3	-2	-1	-1	-1	0
25000	4	3	2	2	1	1	1	0	0	25000	-6	-4	-3	-2	-2	-1	-1	0	0
30000	4	3	3	3	2	1	1	0	0	30000	-6	-4	-3	-2	-1	-1	-1	0	0
35000	5	4	3	3	2	1	1	+1	0	35000	-5	-3	-3	-2	-1	-1	-1	0	0
40000	+5	+4	+3	+3	+2	+2	+1	+1	0	40000	-5	-3	-3	-1	-1	-1	0	0	0

BUBBLE SEXTANT CORIOLIS (Z) CORRECTION							MARINE SEXTANT CORRECTION FOR DIP												
Apply by moving the position line a distance Z to starboard (right) of the track in northern latitudes and to port (left) in southern latitudes.							Subtract from observed altitude.												
							Ht. Dip.		Ht. Dip.		Ht. Dip.		Ht. Dip.		Ht. Dip.				
T.A.S. M.P.H.	Latitude						T.A.S. KNOTS	Ft.		Ft.		Ft.		Ft.		Ft.			
	0°	10°	20°	30°	40°	50°		60°	70°										
100	0	0	1	1	1	2	2	2	87	0	1	114	11	437	21	968	31	1707	41
150	0	0	1	2	2	3	3	3	130	2	2	137	12	481	22	1033	32	1792	42
200	0	1	2	2	3	3	4	4	174	6	2	162	12	527	23	1099	32	1880	42
250	0	1	2	3	4	4	5	5	217	12	3	189	13	575	24	1168	33	1970	43
300	0	1	2	3	4	5	6	6	261	21	4	218	14	625	24	1239	34	2061	44
350	0	1	3	4	5	6	7	7	305	31	5	250	15	677	25	1311	35	2155	45
400	0	1	3	5	6	7	8	9	348	43	6	283	16	731	26	1386	36	2251	46
										58	7	318	17	787	27	1463	37	2349	47
										75	8	356	18	845	28	1543	38	2449	48
										93	9	395	19	906	29	1624	39	2551	49
										114	10	437	20	968	30	1707	40	2655	50

I.—CORRECTION FOR DATE TO TABULATED ALTITUDE OF STARS

t Year	1 2 3 4 5	6 7 8 9 10	11 12 13 14 15	16 17 18 19 20	t Year
1941	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	1941
1942	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	1 1 1 1 1	1942
1943	0 0 0 0 0	0 0 0 0 0	1 1 1 1 1	1 1 1 1 1	1943
1944	0 0 0 0 0	0 0 1 1 1	1 1 1 1 1	1 1 1 1 1	1944
1945	0 0 0 0 0	0 1 1 1 1	1 1 1 1 1	1 1 2 2 2	1945
1946	0 0 0 0 0	1 1 1 1 1	1 1 1 1 2	2 2 2 2 2	1946
1947	0 0 0 0 1	1 1 1 1 1	1 1 2 2 2	2 2 2 2 2	1947
1948	0 0 0 1 1	1 1 1 1 1	1 2 2 2 2	2 2 2 3 3	1948
1949	0 0 0 1 1	1 1 1 1 2	2 2 2 2 2	2 3 3 3 3	1949
1950	0 0 0 1 1	1 1 1 2 2	2 2 2 2 2	3 3 3 3 3	1950
1951	0 0 1 1 1	1 1 1 2 2	2 2 2 3 3	3 3 3 3 4	1951
1952	0 0 1 1 1	1 1 2 2 2	2 2 3 3 3	3 3 4 4 4	1952
1953	0 0 1 1 1	1 2 2 2 2	2 3 3 3 3	3 4 4 4 4	1953
1954	0 0 1 1 1	1 2 2 2 2	3 3 3 3 4	4 4 4 4 5	1954
1955	0 0 1 1 1	2 2 2 2 2	3 3 3 4 4	4 4 4 5 5	1955

16°

DECLINATION CONTRARY NAME TO LATITUDE

16°

LAT.	40°		41°		42°		43°		44°		LAT.
H.A.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	H.A.
45	20 08-49	134	19 26-49	134	18 45-50	134	18 03-50	134	17 21-51	135	315
46	19 34 48	133	18 53 49	133	18 13 50	133	17 31 50	134	16 50 50	134	314
47	19 00 48	132	18 20 48	132	17 40 49	132	16 59 49	133	16 19 50	133	313
48	18 26 48	131	17 47 49	131	17 07 49	132	16 27 49	132	15 47 50	132	312
49	17 51 47	130	17 13 49	131	16 33 48	131	15 54 49	131	15 15 50	131	311
50	17 16-47	130	16 38-48	130	16 00-49	130	15 21-49	130	14 42-49	130	310
51	16 41 47	129	16 03 47	129	15 25 48	129	14 48 49	129	14 09 48	130	309
52	16 05 47	128	15 28 47	128	14 51 48	128	14 14 49	129	13 36 48	129	308
53	15 28 46	127	14 52 47	127	14 16 48	128	13 39 48	128	13 03 49	128	307
54	14 52 46	126	14 16 46	127	13 40 47	127	13 05 48	127	12 28 47	127	306
55	14 15-46	126	13 40-46	126	13 05-47	126	12 29-47	126	11 54-48	126	305
56	13 37 45	125	13 03 46	125	12 29 47	125	11 54 47	125	11 19 47	126	304
57	13 00 45	124	12 26 45	124	11 52 46	125	11 18 46	125	10 44 47	125	303
58	12 22 45	123	11 49 45	124	11 16 46	124	10 42 46	124	10 09-47	124	302
59	11 43 44	123	11 11 45	123	10 39 46	123	10 06-46	123	...	...	301
60	11 05-44	122	10 33-44	122	10 01-45	122	...	...	...	...	300
61	10 26-44	121	...	...	...	...	...	...	...	...	299
62	...	...	...	...	...	...	...	...	...	...	298
63	...	...	...	...	...	...	...	...	...	...	297
64	...	...	...	...	...	...	...	...	...	...	269
65	...	...	...	...	...	...	...	...	...	...	295

In South { For argument H.A. on the left, True Azimuth = $180^\circ + \text{Tabulated Azimuth}$.
 Latitudes { For argument H.A. on the right, True Azimuth = $180^\circ - \text{Tabulated Azimuth}$.

This Table is used for calculating the position line of the planet JUPITER (see Figure 14) and of the Star ALHENA No. 24 (see Figure 15).

H.A.	50°		51°		52°		53°		54°		LAT.
LAT.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	H.A.
0	31 45 +4	180	30 45 +4	180	29 45 +4	180	28 45 +4	180	27 45 +4	180	360
1	31 45 4	179	30 45 4	179	29 45 4	179	28 45 4	179	27 45 4	179	359
2	31 44 4	178	30 44 4	178	29 44 4	178	28 44 4	178	27 44 4	178	358
3	31 42 4	177	30 42 4	177	29 42 4	177	28 42 4	177	27 42 4	177	357
4	31 39 4	175	30 39 4	175	29 39 4	175	28 40 4	175	27 40 4	176	356
5	31 35 +4	174	30 36 +4	174	29 36 +4	174	28 36 +4	174	27 37 +4	174	355
6	31 31 4	173	30 32 4	173	29 32 4	173	28 33 4	173	27 33 4	173	354
7	31 26 4	172	30 27 4	172	29 27 4	172	28 28 4	172	27 29 4	172	353
8	31 20 4	171	30 21 4	171	29 22 4	171	28 23 4	171	27 23 4	171	352
9	31 14 4	170	30 15 4	170	29 16 4	170	28 17 4	170	27 18 4	170	351
10	31 06 +4	168	30 08 +4	169	29 09 +4	169	28 10 +4	169	27 11 +4	169	350
11	30 58 4	167	30 00 4	167	29 01 4	168	28 03 4	168	27 04 4	168	349
12	30 49 4	166	29 51 4	166	28 53 4	166	27 55 4	167	26 56 4	167	348
13	30 40 4	165	29 42 4	165	28 44 4	165	27 46 4	165	26 48 4	166	347
14	30 29 4	164	29 32 4	164	28 34 4	164	27 36 4	164	26 39 4	164	346
15	30 18 +4	163	29 21 +4	163	28 24 +4	163	27 26 +4	163	26 29 +4	163	345
16	30 07 4	162	29 10 4	162	28 13 4	162	27 16 4	162	26 19 4	162	344
17	29 54 4	161	28 57 4	161	28 01 4	161	27 04 4	161	26 08 4	161	343
18	29 41 4	159	28 45 4	160	27 48 4	160	26 52 4	160	25 56 4	160	342
19	29 27 4	158	28 31 4	158	27 35 4	159	26 40 4	159	25 44 4	159	341
20	29 12 +4	157	28 17 +4	157	27 22 +4	158	26 26 +4	158	25 31 +4	158	340
21	28 57 4	156	28 02 4	156	27 07 4	157	26 12 4	157	25 17 4	157	339
22	28 41 4	155	27 47 4	155	26 52 4	155	25 58 5	156	25 03 4	156	338
23	28 24 4	154	27 31 4	154	26 37 4	154	25 43 4	155	24 48 4	155	337
24	28 07 4	153	27 14 4	153	26 20 4	153	25 27 4	154	24 33 4	154	336
25	27 49 +4	152	26 56 +4	152	26 03 +4	152	25 10 +4	152	24 17 +4	153	335
26	27 31 4	151	26 38 4	151	25 46 4	151	24 53 4	151	24 01 4	152	334
27	27 12 4	150	26 20 4	150	25 28 4	150	24 36 4	150	23 44 4	151	333
28	26 52 4	149	26 01 4	149	25 09 4	149	24 18 4	149	23 26 4	150	332
29	26 32 4	148	25 41 4	148	24 50 4	148	23 59 4	148	23 08 4	149	331
30	26 11 +4	147	25 21 +4	147	24 30 +4	147	23 40 +4	147	22 49 +4	148	330
31	25 49 4	146	25 00 4	146	24 10 4	146	23 20 4	146	22 30 4	147	329
32	25 27 4	145	24 38 4	145	23 49 4	145	23 00 4	145	22 11 4	146	328
33	25 04 4	143	24 16 4	144	23 28 4	144	22 39 4	144	21 50 4	145	327
34	24 41 4	142	23 54 4	143	23 06 4	143	22 18 4	143	21 30 4	144	326
35	24 17 +4	141	23 30 +4	142	22 43 +4	142	21 56 +4	142	21 09 +4	143	325
36	23 53 4	141	23 07 4	141	22 20 4	141	21 34 4	141	20 47 4	142	324
37	23 28 4	140	22 43 4	140	21 57 4	140	21 11 4	140	20 25 4	141	323
38	23 03 4	139	22 18 4	139	21 33 4	139	20 48 4	139	20 02 4	140	322
39	22 38 4	138	21 53 4	138	21 09 4	138	20 24 4	138	19 39 4	139	321
40	22 11 +4	137	21 28 +4	137	20 44 +4	137	20 00 +4	137	19 16 +4	138	320
41	21 45 4	136	21 02 4	136	20 19 4	136	19 35 4	136	18 52 4	137	319
42	21 17 4	135	20 35 4	135	19 53 4	135	19 10 4	135	18 27 4	136	318
43	20 50 4	134	20 08 4	134	19 27 4	134	18 45 4	135	18 03 4	135	317
44	20 22 4	133	19 41 4	133	19 00 4	133	18 19 4	134	17 37 4	134	316
45	19 53 +4	132	19 13 +4	132	18 33 +4	132	17 53 +4	133	17 12 +4	133	315

For argument H.A. on the left, True Azimuth = 360° - Tabulated Azimuth.

For argument H.A. on the right, True Azimuth = Tabulated Azimuth.

No correction for date is necessary until 1955.

This Table is used for calculating the position line of the Star RIGEL No. 18 (see Figure 13).

CONVERSION OF ARC TO TIME

0	0 00	60	4 00	120	8 00	180	12 00	240	16 00	300	20 00	0	0 00
1	0 04	61	4 04	121	8 04	181	12 04	241	16 04	301	20 04	1	0 04
2	0 08	62	4 08	122	8 08	182	12 08	242	16 08	302	20 08	2	0 08
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12	3	0 12
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16	4	0 16
5	0 20	65	4 20	125	8 20	185	12 20	245	16 20	305	20 20	5	0 20
6	0 24	66	4 24	126	8 24	186	12 24	246	16 24	306	20 24	6	0 24
7	0 28	67	4 28	127	8 28	187	12 28	247	16 28	307	20 28	7	0 28
8	0 32	68	4 32	128	8 32	188	12 32	248	16 32	308	20 32	8	0 32
9	0 36	69	4 36	129	8 36	189	12 36	249	16 36	309	20 36	9	0 36
10	0 40	70	4 40	130	8 40	190	12 40	250	16 40	310	20 40	10	0 40
11	0 44	71	4 44	131	8 44	191	12 44	251	16 44	311	20 44	11	0 44
12	0 48	72	4 48	132	8 48	192	12 48	252	16 48	312	20 48	12	0 48
13	0 52	73	4 52	133	8 52	193	12 52	253	16 52	313	20 52	13	0 52
14	0 56	74	4 56	134	8 56	194	12 56	254	16 56	314	20 56	14	0 56
15	1 00	75	5 00	135	9 00	195	13 00	255	17 00	315	21 00	15	1 00
16	1 04	76	5 04	136	9 04	196	13 04	256	17 04	316	21 04	16	1 04
17	1 08	77	5 08	137	9 08	197	13 08	257	17 08	317	21 08	17	1 08
18	1 12	78	5 12	138	9 12	198	13 12	258	17 12	318	21 12	18	1 12
19	1 16	79	5 16	139	9 16	199	13 16	259	17 16	319	21 16	19	1 16
20	1 20	80	5 20	140	9 20	200	13 20	260	17 20	320	21 20	20	1 20
21	1 24	81	5 24	141	9 24	201	13 24	261	17 24	321	21 24	21	1 24
22	1 28	82	5 28	142	9 28	202	13 28	262	17 28	322	21 28	22	1 28
23	1 32	83	5 32	143	9 32	203	13 32	263	17 32	323	21 32	23	1 32
24	1 36	84	5 36	144	9 36	204	13 36	264	17 36	324	21 36	24	1 36
25	1 40	85	5 40	145	9 40	205	13 40	265	17 40	325	21 40	25	1 40
26	1 44	86	5 44	146	9 44	206	13 44	266	17 44	326	21 44	26	1 44
27	1 48	87	5 48	147	9 48	207	13 48	267	17 48	327	21 48	27	1 48
28	1 52	88	5 52	148	9 52	208	13 52	268	17 52	328	21 52	28	1 52
29	1 56	89	5 56	149	9 56	209	13 56	269	17 56	329	21 56	29	1 56
30	2 00	90	6 00	150	10 00	210	14 00	270	18 00	330	22 00	30	2 00
31	2 04	91	6 04	151	10 04	211	14 04	271	18 04	331	22 04	31	2 04
32	2 08	92	6 08	152	10 08	212	14 08	272	18 08	332	22 08	32	2 08
33	2 12	93	6 12	153	10 12	213	14 12	273	18 12	333	22 12	33	2 12
34	2 16	94	6 16	154	10 16	214	14 16	274	18 16	334	22 16	34	2 16
35	2 20	95	6 20	155	10 20	215	14 20	275	18 20	335	22 20	35	2 20
36	2 24	96	6 24	156	10 24	216	14 24	276	18 24	336	22 24	36	2 24
37	2 28	97	6 28	157	10 28	217	14 28	277	18 28	337	22 28	37	2 28
38	2 32	98	6 32	158	10 32	218	14 32	278	18 32	338	22 32	38	2 32
39	2 36	99	6 36	159	10 36	219	14 36	279	18 36	339	22 36	39	2 36
40	2 40	100	6 40	160	10 40	220	14 40	280	18 40	340	22 40	40	2 40
41	2 44	101	6 44	161	10 44	221	14 44	281	18 44	341	22 44	41	2 44
42	2 48	102	6 48	162	10 48	222	14 48	282	18 48	342	22 48	42	2 48
43	2 52	103	6 52	163	10 52	223	14 52	283	18 52	343	22 52	43	2 52
44	2 56	104	6 56	164	10 56	224	14 56	284	18 56	344	22 56	44	2 56
45	3 00	105	7 00	165	11 00	225	15 00	285	19 00	345	23 00	45	3 00
46	3 04	106	7 04	166	11 04	226	15 04	286	19 04	346	23 04	46	3 04
47	3 08	107	7 08	167	11 08	227	15 08	287	19 08	347	23 08	47	3 08
48	3 12	108	7 12	168	11 12	228	15 12	288	19 12	348	23 12	48	3 12
49	3 16	109	7 16	169	11 16	229	15 16	289	19 16	349	23 16	49	3 16
50	3 20	110	7 20	170	11 20	230	15 20	290	19 20	350	23 20	50	3 20
51	3 24	111	7 24	171	11 24	231	15 24	291	19 24	351	23 24	51	3 24
52	3 28	112	7 28	172	11 28	232	15 28	292	19 28	352	23 28	52	3 28
53	3 32	113	7 32	173	11 32	233	15 32	293	19 32	353	23 32	53	3 32
54	3 36	114	7 36	174	11 36	234	15 36	294	19 36	354	23 36	54	3 36
55	3 40	115	7 40	175	11 40	235	15 40	295	19 40	355	23 40	55	3 40
56	3 44	116	7 44	176	11 44	236	15 44	296	19 44	356	23 44	56	3 44
57	3 48	117	7 48	177	11 48	237	15 48	297	19 48	357	23 48	57	3 48
58	3 52	118	7 52	178	11 52	238	15 52	298	19 52	358	23 52	58	3 52
59	3 56	119	7 56	179	11 56	239	15 56	299	19 56	359	23 56	59	3 56

The above table is for converting expressions in arc to their equivalent in time; its main use in this Almanac is for the conversion of longitude for application to L.M.T. (*added if west, subtracted if east*) to give G.M.T. or vice versa, particularly in the case of sunrise, sunset, etc.

4°

DECLINATION **SAME** NAME AS LATITUDE

4°

LAT.	40°		41°		42°		43°		44°		LAT.
H.A.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	H.A.
0	54 01+60	180	53 01+60	180	52 01+60	180	51 01+60	180	50 01+60	180	360
1	54 00 60	178	53 00 60	178	52 00 60	178	51 00 60	178	50 00 60	178	359
2	53 58 60	177	52 58 60	177	51 58 60	177	50 58 60	177	49 58 60	177	358
3	53 54 60	175	52 55 60	175	51 55 60	175	50 55 60	175	49 55 60	175	357
4	53 50 59	173	52 50 60	173	51 51 59	174	50 51 60	174	49 51 60	174	356
5	53 44+59	172	53 44+60	172	51 45+60	172	50 46+59	172	49 46+60	172	355
6	53 36 60	170	52 37 60	170	51 38 60	170	50 39 59	171	49 40 59	171	354
7	53 28 59	168	52 29 59	168	51 30 59	169	50 31 59	169	49 32 60	169	353
8	53 17 59	167	52 19 59	167	51 21 59	167	50 22 59	167	49 24 59	168	352
9	53 06 59	165	52 08 59	165	51 10 59	166	50 12 59	166	49 14 59	166	351
10	52 54+58	163	51 56+59	164	50 58+59	164	50 01+59	164	49 03+59	165	350
11	52 40 58	162	51 43 58	162	50 46 58	163	49 48 59	163	48 51 59	163	349
12	52 25 58	160	51 28 58	161	50 32 58	161	49 35 58	161	48 38 58	162	348
13	52 09 57	159	51 13 57	159	50 17 57	159	49 20 58	160	48 24 58	160	347
14	51 51 57	157	50 56 57	158	50 00 58	158	49 05 57	158	48 09 58	159	346
15	51 33+56	155	50 38+57	156	49 43+57	156	48 48+57	157	47 53+57	157	345
16	51 13 56	154	50 19 57	155	49 25 57	155	48 30 57	155	47 36 57	156	344
17	50 52 56	152	49 59 56	153	49 05 57	154	48 12 56	154	47 18 57	155	343
18	50 31 55	151	49 38 56	152	48 45 56	152	47 52 56	153	46 59 56	153	342
19	50 08 55	150	49 16 55	150	48 24 56	151	47 31 56	151	46 39 56	152	341
20	49 44+55	148	48 53+55	149	48 02+55	149	47 10+56	150	46 18+56	150	340
21	49 19 55	147	48 29 55	147	47 38 55	148	46 47 56	149	45 56 56	149	339
22	48 54 54	145	48 04 54	146	47 14 55	147	46 24 55	147	45 33 56	148	338
23	48 27 54	144	47 38 54	145	46 49 54	145	46 00 54	146	45 10 55	146	337
24	48 00 53	143	47 12 53	143	46 24 53	144	45 35 54	145	44 46 54	145	336
25	47 31+53	141	46 44+53	142	45 57+53	143	45 09+54	143	44 21+54	144	335
26	47 02 52	140	46 16 53	141	45 29 53	141	44 42 54	142	43 55 54	143	334
27	46 33 51	139	45 47 52	140	45 01 53	140	44 15 53	141	43 28 54	141	333
28	46 02 51	138	45 17 52	138	44 32 53	139	43 47 53	140	43 01 53	140	332
29	45 31 50	136	44 47 51	137	44 03 52	138	43 18 52	138	42 33 53	139	331
30	44 59+50	135	44 16+51	136	43 32+52	137	42 49+52	137	42 04+53	138	330
31	44 26 50	134	43 44 50	135	43 01 51	135	42 19 51	136	41 35 52	137	329
32	43 52 50	133	43 11 50	134	42 30 50	134	41 48 51	135	41 05 52	135	328
33	43 18 49	132	42 38 50	132	41 58 50	133	41 16 51	134	40 35 51	134	327
34	42 44 48	131	42 05 49	131	41 25 50	132	40 44 51	133	40 04 50	133	326
35	42 09+48	130	41 30+49	130	40 51+50	131	40 12+50	132	39 32+50	132	325
36	41 33 48	128	40 55 49	129	40 17 49	130	39 39 49	130	39 00 50	131	324
37	40 57 47	127	40 20 48	128	39 43 48	129	39 05 49	129	38 27 50	130	323
38	40 20 47	126	39 44 48	127	39 08 48	128	38 31 49	128	37 53 50	129	322
39	39 43 46	125	39 08 47	126	38 32 48	127	37 56 49	127	37 20 49	128	321
40	39 05+46	124	38 31+47	125	37 56+48	126	37 21+48	126	36 45+49	127	320
41	38 27 46	123	37 54 46	124	37 20 47	125	36 46 47	125	36 11 48	126	319
42	37 48 46	122	37 16 46	123	36 43 47	124	36 09 48	124	35 35 49	125	318
43	37 09 45	121	36 38 46	122	36 06 46	123	35 33 47	123	35 00 48	124	317
44	36 30 45	120	35 59 46	121	35 28 46	122	34 56 47	122	34 24 47	123	316
45	35 50+45	120	35 20+45	120	34 50+46	121	34 19+47	121	33 47+48	122	315

This Table is used for calculating the position
line of the SUN. (See Figure 17.)

In North { For argument H.A. on the left, True Azimuth = 360° - Tabulated Azimuth.
Latitudes { For argument H.A. on the right, True Azimuth = Tabulated Azimuth.

CORRECTIONS FOR HEIGHT

TO TABULATED TIMES OF SUNRISE, SUNSET AND TWILIGHT

LATITUDES—NORTH 67°-72°

Correction S to be subtracted from time of sunrise, added to time of sunset.

Correction T to be subtracted from time of morning twilight, added to time of evening twilight.

Height in feet	1,000 S T	5,000 S T	10,000 S T	15,000 S T	20,000 S T	30,000 S T	40,000 S T	1,000 S T	5,000 S T	10,000 S T	15,000 S T	20,000 S T	30,000 S T	40,000 S T
Date	Latitude North 67°							Latitude North 68°						
Dec. 31	V 0	V 2	V 5	V 7	V 9	V 14	V 18	V 0	V 2	V 5	V 8	V 10	V 15	V 20
Jan. 4	17 0	36 2	47 5	56 7	62 9	73 14	82 18	27 0	49 2	65 5	76 8	83 10	96 14	V 19
Jan. 9	15 0	32 2	43 4	51 7	57 9	67 13	75 17	20 0	39 2	54 5	64 7	72 9	82 14	90 19
Jan. 13	13 0	28 2	38 4	45 7	51 9	61 13	69 17	17 0	33 2	45 5	54 7	62 9	72 13	80 18
Jan. 18	11 0	24 2	34 4	40 6	45 8	55 12	63 16	14 0	28 2	38 4	46 6	52 8	63 13	70 17
Jan. 24	9 0	21 2	30 4	36 6	41 7	49 11	56 15	11 0	24 2	33 4	39 6	44 7	54 12	60 16
Feb. 1	8 0	17 2	24 3	29 5	34 6	41 10	47 13	8 0	19 2	26 4	31 6	36 7	44 11	50 14
Feb. 12	7 0	15 2	21 3	26 5	30 6	37 10	42 13	7 0	16 2	22 3	27 5	32 6	38 10	45 13
Apr. 10	7 0	15 2	22 4	27 7	32 9	40 13	46 17	8 0	17 2	24 5	29 8	34 10	42 14	50 19
Apr. 21	8 1	18 3	26 6	32 9	38 12	47 18	55 24	9 1	20 3	29 7	35 11	41 14	52 21	60 28
Apr. 28	9 1	20 4	29 8	36 12	42 16	52 24	61 32	10 1	22 6	32 13	40 18	47 22	59 39	70 L
May 1														
	Latitude North 69°							Latitude North 70°						
Dec. 31	V 1	V 3	V 6	V 9	V 12	V 16	V 21	V 1	V 4	V 7	V 10	V 13	V 19	V 24
Jan. 17	18 1	37 3	50 5	59 8	65 10	78 14	85 19	33 1	61 3	78 6	91 9	99 11	V 16	V 20
Jan. 19	16 1	34 3	45 5	54 8	61 10	72 14	80 18	24 1	47 3	61 5	71 8	78 10	91 15	99 19
Jan. 21	15 1	31 2	42 5	50 7	57 9	67 14	76 17	19 1	39 3	53 5	62 8	69 10	80 15	90 19
Jan. 24	13 1	28 2	39 5	46 7	52 9	62 13	70 17	16 1	33 3	46 5	55 8	61 10	72 14	80 18
Jan. 27	11 0	24 2	34 4	41 7	46 9	55 12	63 16	13 1	28 2	38 5	46 7	52 9	61 13	70 17
Feb. 2	9 0	21 2	29 4	35 6	40 8	48 12	55 15	11 1	23 2	32 4	39 6	44 8	52 12	60 16
Feb. 12	8 0	17 2	24 4	29 6	34 8	41 12	47 15	9 1	19 2	26 4	31 6	36 8	44 13	50 16
Apr. 11	8 1	19 3	26 6	32 9	38 11	47 17	55 22	9 1	20 3	28 7	35 10	41 13	51 19	60 25
Apr. 20	9 1	21 4	29 8	36 12	43 15	53 23	63 31	10 1	23 5	32 10	40 16	47 21	59 32	70 45
Apr. 25	10 1	22 5	32 10	40 16	47 21	59 33	70 48	11 2	25 9	36 21	45 L	53 L	68 L	80 L
Apr. 27	10 1	23 7	34 14	42 22	50 30	64 L	76 L	11 L	27 L	39 L	49 L	57 L	74 L	90 L
Apr. 29	11 L	25 L	36 L	45 L	54 L	68 L	82 L	12 L	29 L	41 L	52 L	62 L	82 L	99 L
May 1														
	Latitude North 71°							Latitude North 72°						
Dec. 31	V 1	V 4	V 8	V 12	V 15	V 21	V 27	V 2	V 6	V 11	V 16	V 20	V 29	V 35
Jan. 23	28 1	56 3	69 6	79 9	86 11	99 16	V 21	V 1	V 3	V 7	V 10	V 12	V 19	V 23
Jan. 24	23 1	46 3	60 6	71 9	79 11	90 16	99 20	V 1	V 3	V 6	V 9	V 12	V 17	V 22
Jan. 26	19 1	38 3	52 5	61 8	68 10	81 15	90 19	31 1	62 3	79 6	91 9	99 12	V 17	V 21
Jan. 28	17 1	34 3	46 5	55 8	62 10	73 15	82 19	22 1	44 3	60 6	70 9	77 11	90 16	99 20
Jan. 30	15 1	31 3	42 5	51 8	58 10	68 14	77 18	19 1	38 3	52 5	62 8	69 11	80 15	90 20
Feb. 2	13 1	28 2	38 5	46 7	52 9	63 13	70 18	15 1	33 3	45 5	54 8	60 10	71 15	80 19
Feb. 6	11 0	23 2	34 5	41 7	47 9	56 13	63 17	13 1	28 2	38 5	46 7	52 9	62 14	70 18
Feb. 12	9 0	21 2	29 4	35 6	40 8	49 12	56 16	11 1	23 2	32 5	39 7	44 9	52 13	60 17
Feb. 20	9 0	19 2	26 4	31 7	36 9	45 13	51 17	9 1	20 2	28 5	34 7	39 9	47 13	55 18
Apr. 5	9 1	19 3	27 6	33 9	39 11	48 16	55 21	9 1	20 3	29 6	36 9	42 12	53 16	60 24
Apr. 11	9 1	21 5	30 7	37 11	43 14	54 20	65 27	10 1	23 4	33 8	41 13	47 17	59 25	70 33
Apr. 17	10 1	23 5	33 9	41 14	47 19	59 29	71 40	11 1	25 7	36 14	45 23	53 31	67 L	80 L
Apr. 20	11 1	24 6	35 12	43 19	50 26	64 43	77 L	12 3	27 L	39 L	49 L	57 L	74 L	90 L
Apr. 22	11 2	25 8	36 17	45 31	53 44	67 L	81 L	12 L	28 L	41 L	52 L	61 L	79 L	99 L
Apr. 24	12 L	28 L	40 L	50 L	60 L	78 L	93 L	14 L	32 L	48 L	61 L	73 L	99 L	U U
Apr. 27	13 L	30 L	45 L	57 L	67 L	90 L	U U	15 L	36 L	55 L	77 L	99 L	U U	U U
Apr. 31	15 L	36 L	56 L	77 L	99 L	U U	U U	19 L	45 L	99 L	U U	U U	U U	U U
May 1														

The symbol V indicates that the Sun may be visible for a short while only at noon.

The symbol L (light) indicates that it is light (i.e. lighter than at civil twilight) at midnight.

The symbol U (up) indicates that the Sun is above the horizon at midnight.

XV.—CORRECTION TO TABULATED ALTITUDE FOR MINUTES OF DECLINATION

d	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	d
00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	00
01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	01
02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	02
03	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	03
04	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	04
05	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	05
06	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	06
07	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	07
08	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	08
09	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	09
10	0	0	0	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	5	5	10
11	0	0	1	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	11
12	0	0	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	6	6	12
13	0	0	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	13
14	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	7	7	14
15	0	0	1	1	1	2	2	2	2	2	3	3	3	4	4	4	4	4	5	5	5	6	6	6	6	6	7	7	7	8	15
16	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	5	5	5	5	6	6	6	6	7	7	7	8	8	8	16
17	0	1	1	1	1	2	2	2	3	3	3	3	4	4	4	4	5	5	5	6	6	6	7	7	7	7	8	8	8	8	17
18	0	1	1	1	2	2	2	2	3	3	3	4	4	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	18
19	0	1	1	1	2	2	2	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	19
20	0	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	20
21	0	1	1	1	2	2	2	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	10	21
22	0	1	1	1	2	2	3	3	3	4	4	4	5	5	6	6	6	7	7	7	8	8	8	9	9	10	10	10	11	11	22
23	0	1	1	1	2	2	3	3	3	4	4	5	5	5	6	6	7	7	7	8	8	8	9	9	10	10	10	11	11	12	23
24	0	1	1	1	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	8	8	9	9	10	10	10	11	12	12	12	24
25	0	1	1	1	2	2	3	3	4	4	5	5	5	6	6	7	7	8	8	8	9	9	10	10	10	11	11	12	12	12	25
26	0	1	1	1	2	2	3	3	4	4	5	5	6	6	6	7	7	8	8	9	9	10	10	10	11	11	12	12	13	13	26
27	0	1	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	9	10	10	11	11	12	12	13	13	14	27
28	0	1	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	28
29	0	1	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	29
30	0	1	2	2	2	3	4	4	4	5	6	6	6	7	8	8	8	9	10	10	10	11	12	12	12	13	13	14	14	15	30
31	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	16	31
32	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15	16	32
33	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	10	11	11	12	12	13	13	14	14	15	15	16	16	33
34	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	10	10	11	11	12	12	13	13	14	14	15	15	16	16	34
35	1	1	2	2	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	12	12	13	13	14	14	15	15	16	17	35
36	1	1	2	2	3	4	4	5	5	6	7	7	7	8	8	9	10	10	11	11	12	13	13	14	14	15	15	16	17	17	36
37	1	1	2	2	3	4	4	5	6	6	7	7	7	8	9	9	10	10	11	12	12	13	14	14	15	15	16	17	17	18	37
38	1	1	2	2	3	4	4	5	6	6	7	8	8	9	9	10	10	11	11	12	13	13	14	14	15	15	16	17	18	18	38
39	1	1	2	2	3	4	4	5	6	6	7	8	8	9	10	10	11	12	12	13	13	14	14	15	15	16	17	18	18	19	39
40	1	1	2	2	3	4	4	5	6	7	7	8	9	9	10	11	11	12	13	13	14	14	15	15	16	17	17	18	19	19	40
41	1	1	2	2	3	4	4	5	6	7	8	8	9	10	10	11	12	12	13	13	14	14	15	15	16	17	18	18	19	20	41
42	1	1	2	2	3	4	4	5	6	7	8	8	9	10	10	11	12	13	13	14	14	15	15	16	17	18	18	19	20	21	42
43	1	1	2	2	3	4	4	5	6	7	8	9	9	10	11	11	12	13	13	14	14	15	15	16	17	18	19	19	20	21	43
44	1	1	2	2	3	4	4	5	6	7	7	8	9	10	10	11	12	12	13	13	14	14	15	15	16	17	18	18	19	20	44
45	1	2	2	2	3	4	4	5	6	7	8	8	9	10	10	11	12	13	13	14	14	15	15	16	17	18	19	20	21	22	45
46	1	2	2	2	3	4	5	5	6	7	8	8	9	10	11	12	12	13	13	14	14	15	15	16	17	18	19	20	21	22	46
47	1	2	2	2	3	4	5	5	6	7	8	9	9	10	11	12	13	13	14	14	15	15	16	17	18	19	20	21	22	23	47
48	1	2	2	2	3	4	5	6	6	7	8	9	10	10	11	12	13	14	14	15	15	16	17	18	18	19	20	21	22	23	48
49	1	2	2	2	3	4	5	6	7	7	8	9	10	11	11	12	13	14	14	15	15	16	17	18	18	19	20	21	22	23	49
50	1	2	2	2	3	4	5	6	7	8	8	9	10	11	12	12	13	14	14	15	15	16	17	18	18	19	20	21	22	23	50
51	1	2	3	3	4	5	6	7	8	8	9	10	11	12	13	13	14	14	15	15	16	17	18	19	20	21	22	23	24	25	51
52	1	2	3	3	4	5	6	7	8	9	10	10	11	12	13	14	14	15	15	16	17	18	19	20	21	22	23	23	24	25	52
53	1	2	3	3	4	5	6	7	8	9	10	11	11	12	13	14	14	15	15	16	17	18	19	20	21	22	23	24	25	26	53
54	1	2	3	3	4	5	6	7	8	9	10	11	12	13	14	14	15	15	16	17	18	19	20	21	22	23	24	24	25	26	54
55	1	2	3	3	4	5	6	7	8	9	10	11	12	13	14	14	15	15	16	17	18	19	20	21	22	23	24	24	25	26	55
56	1	2	3	3	4	5	6	7	7	8	9	10	11	12	13	14	14	15	15	16	17	18	19	20	21	21	22	23	24	25	56
57	1	2	3	3	4	5	6	7	8	9	10	10	11	12	13	14	14	15	15	16	17	18	19	20	2						

XV.—CORRECTION TO TABULATED ALTITUDE FOR MINUTES OF DECLINATION

d	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	d
00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	00
01	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	01
02	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	02
03	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	03
04	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	04
05	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	05
06	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6	06
07	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	7	7	7	7	7	07
08	4	4	4	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	8	8	8	8	08
09	5	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7	7	7	7	8	8	8	8	8	8	8	9	9	9	9	09
10	5	5	6	6	6	6	6	6	6	7	7	7	7	7	8	8	8	8	8	8	8	9	9	9	9	9	10	10	10	10	10
11	6	6	6	6	6	7	7	7	7	7	8	8	8	8	8	8	9	9	9	9	9	10	10	10	10	10	10	11	11	11	11
12	6	6	7	7	7	7	7	8	8	8	8	8	8	8	9	9	9	9	10	10	10	10	11	11	11	11	11	11	12	12	12
13	7	7	7	7	8	8	8	8	8	9	9	9	9	10	10	10	10	10	11	11	11	11	11	12	12	12	12	13	13	13	13
14	7	7	8	8	8	8	9	9	9	9	10	10	10	10	10	11	11	11	11	12	12	12	12	13	13	13	13	14	14	14	14
15	8	8	8	8	9	9	9	10	10	10	10	10	11	11	11	12	12	12	12	13	13	13	14	14	14	14	15	15	15	15	15
16	8	9	9	9	9	10	10	10	10	11	11	11	11	12	12	12	13	13	13	14	14	14	14	15	15	15	16	16	16	16	16
17	9	9	9	10	10	10	10	11	11	11	12	12	12	12	13	13	14	14	14	15	15	15	15	16	16	16	16	17	17	17	17
18	9	10	10	10	10	11	11	11	12	12	12	13	13	13	14	14	14	15	15	15	15	16	16	16	16	17	17	17	18	18	18
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55	28	29																													

CHAPTER VIII

MAGNETISM AND COMPASSES

"Where do you come from?" said the Queen, "and where are you going?"

—"Alice Through the Looking Glass."

Magnetism

1. Natural magnetism is found in certain mineral substances such as lodestone. Magnetism may also be induced in iron or steel by certain physical methods.

The properties of both natural and induced magnets are the same. A substance is magnetic if :—

- (i) It attracts pieces of iron and steel which are not magnetized.
- (ii) It attracts or repels other magnets.
- (iii) When suspended so as to be able to rotate freely in the horizontal plane, it comes to rest in a particular direction. If it is deflected from this position of rest, it oscillates about the position and finally resumes the same attitude. This is a result of (ii) since the earth itself is a large magnet.

2. If a magnetized body is dipped into iron filings, it is found that the filings cling strongly to the ends of the magnet but comparatively feebly to the central portion. It appears that most of the magnetism in the body is concentrated at two points. These points which are not exactly at the ends, but very nearly so, are called the poles of the magnet. If the magnet is freely suspended, the magnetic axis, *i.e.*, the line joining the poles, lies approximately North and South. One pole is called the North-Seeking or Red Pole, and the other the South-Seeking or Blue Pole.

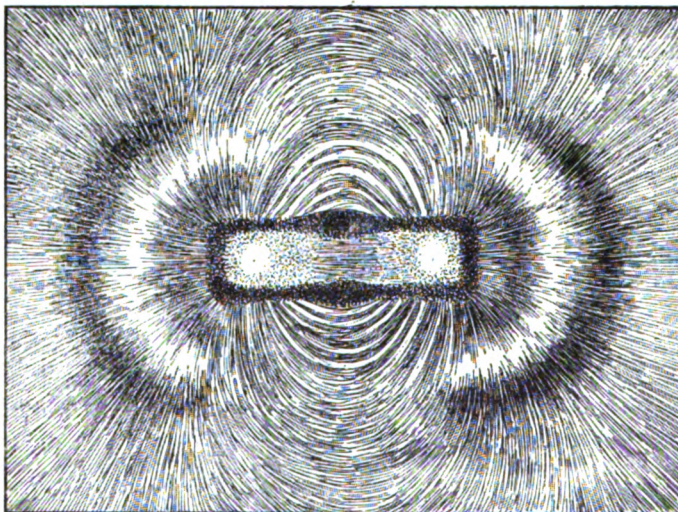


FIGURE 1. Arrangement of Iron Filings above a Magnet, showing position of Poles and Lines of Force.

3. When a magnet is brought close to another magnet which is freely suspended, it is found that the two Red Poles or the two Blue Poles repel each other, but that a Red Pole and a Blue Pole attract each other. Hence the important rule :

Like poles repel each other, unlike poles attract each other.

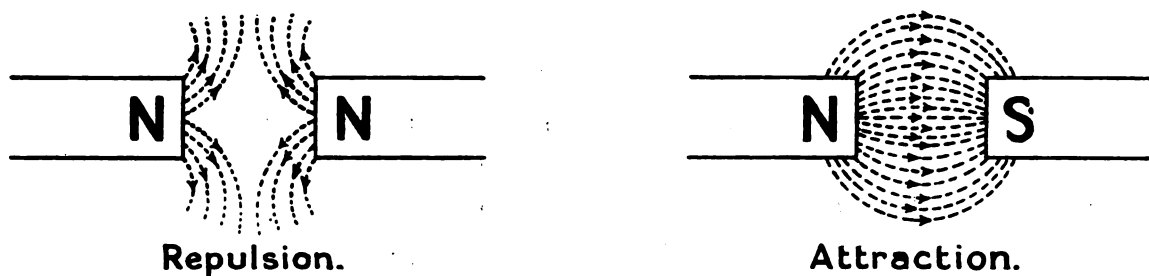


FIGURE 2. Like Poles Repel, Unlike Poles attract each other.

4. A part of space where there are magnetic forces present is called a magnetic field. This field can be mapped by moving a small compass needle over it and drawing a small line at each point to represent the direction in which the needle points. The aggregate of these constitutes the lines of force which may be defined thus:—

A line of force is a curve drawn in the magnetic field so that the tangent to it at any point gives the direction of the magnetic force at that point.

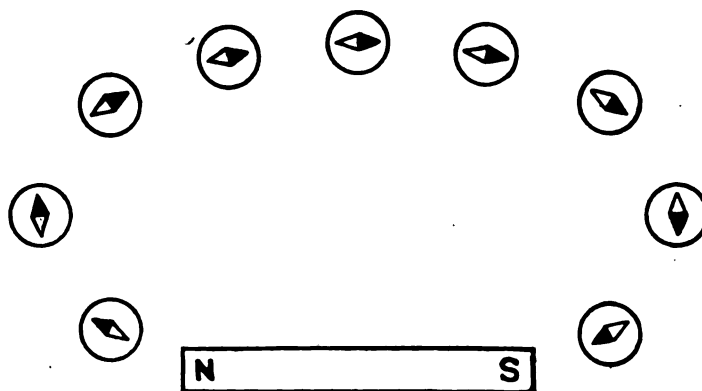


FIGURE 3. Compass Needle in Magnetic Field.

The Molecular Theory of Magnetization

5. Magnetic material which has not been magnetized is made up of a very large number of very small magnets whose axes are scattered at random in all possible directions.

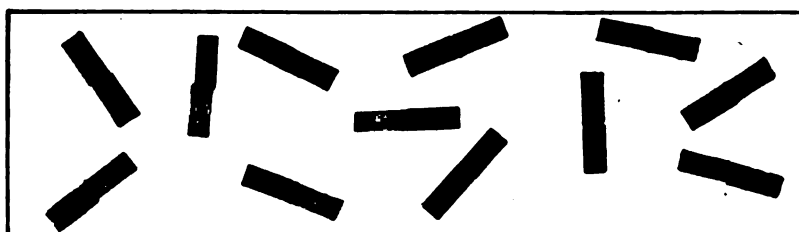


FIGURE 4. Molecular Magnets scattered in a Steel Bar before Magnetization.

The many fields of the molecular magnets neutralize each other, and so the bar as a whole does not behave as a magnet. If, however, the axes of the small magnets are all made to point in the same direction, then their magnetic fields reinforce each other.

The bar will now possess magnetic properties: it has become magnetized. The degree of magnetization depends upon the degree of alignment of the small magnets. The limit is reached when all the magnets are in line. The material is then said to be magnetically saturated.

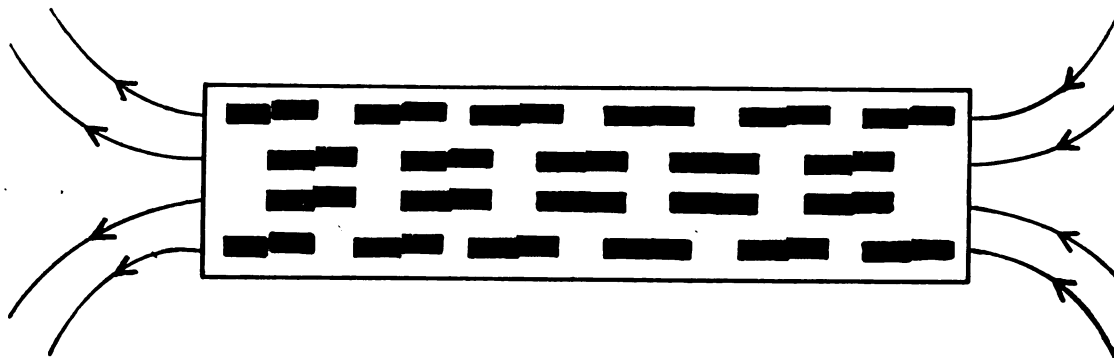


FIGURE 5. The Molecular Magnets aligned after Magnetization of a Steel Bar.

If a magnet is broken up into a number of small pieces, it is found that each of these pieces is itself a magnet with a red pole and a blue pole, but it is impossible to obtain an isolated red or blue pole no matter how far the breaking-up process is continued.

The Magnetic Characteristics of Hard and Soft Iron

6. The ease with which the molecular magnets can be aligned classifies magnetic material into "hard" and "soft" varieties. Metals of the "hard" type are difficult to magnetize, but, once magnetized, retain that property for a considerable length of time. On the other hand, metals of the "soft" type are easily magnetized, but generally lose that property once the magnetizing force has been removed. Wrought iron is generally of the "soft" type, while cobalt and tungsten steels are of the "hard" type.

Some Methods of Magnetization

7. (i) *By Induction.*

If a piece of magnetically-neutral iron or steel is placed in a magnetic field, the molecular magnets will tend to leave their haphazard arrangement and align themselves along the lines of force with their Red Poles towards the Blue-Pole of the magnetizing field. In this way, the metal becomes magnetized. Therefore when magnetically-neutral material is placed near a magnet it becomes a second magnet which will react upon the first. (In the case of hard metals, hammering may be necessary to assist the alignment process.)

(ii) *By Stroking.*

The piece of metal to be magnetized is laid flat and stroked in one direction only with one pole of a powerful magnet. If a red pole is used, the blue poles of the metal's elementary magnets will try to follow the red stroking pole, and thus re-arrange themselves into the required lines. If a greater effect is desired, the blue pole of one magnet and the red pole of another should be used, stroking outwards from the centre in opposite directions.

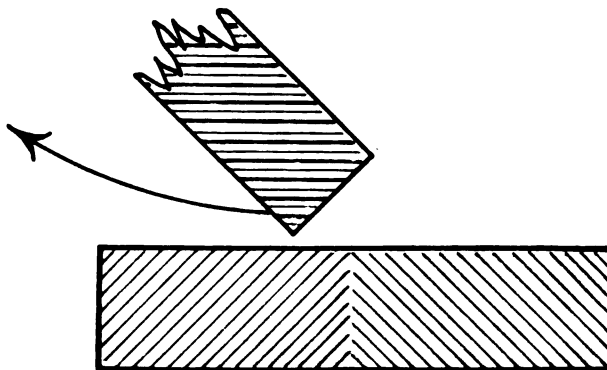


FIGURE 6. Magnetization by Stroking.

(iii) *By Solenoid.*

When an electric current passes through a coil of wire, the coil of wire becomes a magnet (*see* para. 11). Such coils of wire are called **Solenoids**.

If a piece of metal to be magnetized is placed within such a coil, and the current switched on, magnetization of the metal will take place by induction (*see* Fig. 7). This method is generally used when a powerful magnetizing force is required, as in the case of the "hard" cobalt steel magnets of an aircraft compass.

Magnetic Saturation

8. The magnetization of a piece of metal can be continued to any desired degree of intensity until a point is reached beyond which further application of the magnetizing force produces no increase in the magnetic strength of the metal. When this point is reached, the metal is said to be magnetically "saturated."

De-Magnetization

9. A magnetized piece of metal can be de-magnetized by jumbling up the elementary magnets in the metal, or disturbing the orderly arrangement necessary for the formation of an external magnetic field. In the case of "soft" iron this can be done by merely removing the magnetizing force. "Hard" iron presents a rather more difficult problem.

10. A very thorough method of de-magnetizing "hard" iron is used when treating aircraft components such as undercarriages, movable flap gear and so forth. A single-phase alternating current (in the order of 250 volts, 50 cycles) is sent through the winding of a large solenoid, and the component to be de-magnetized is then passed from one end to the other through the middle of the coil.

The current is then reduced, and the component again passed through the coil in the same direction. The alternating magnetic field of the coil, when applied in this manner, is sufficient to jumble up the elementary magnets in the metal and de-magnetize it completely.

Other methods of de-magnetization include heating the metal to a certain temperature and hammering it in a field of opposite polarity. Either of these methods will jumble up the elementary magnets of the metal, though the heating method is probably the most thorough.

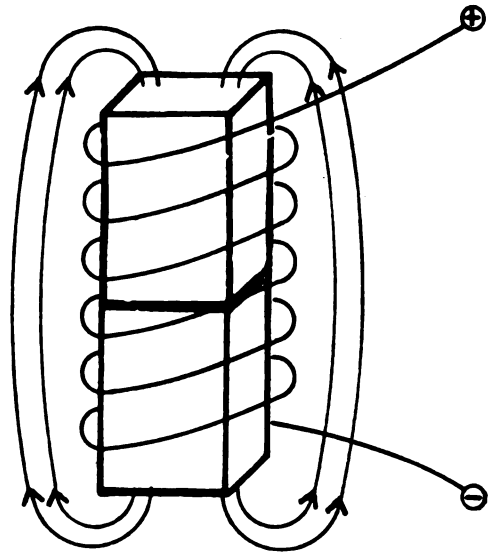


FIGURE 7. Magnetization by Solenoid.

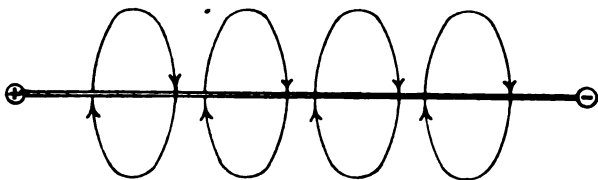


FIGURE 8 (a). Magnetic Field Produced by Electric Current in a Wire.

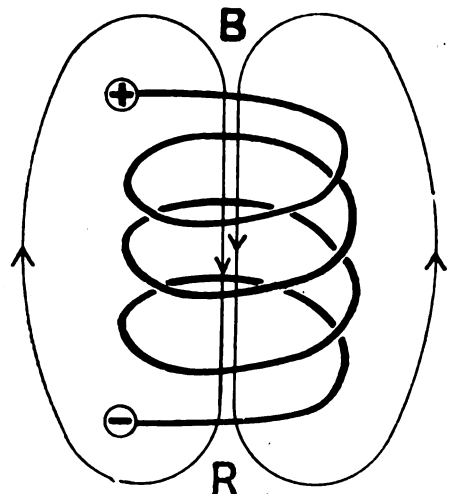


FIGURE 8 (b). Magnetic Field Produced by Electric Current in a Solenoid.

Magnetic Properties of an Electric Current

11. If an electric current is flowing along a straight piece of wire it produces a magnetic field around the wire as shown in Fig. 8. The field is built up of innumerable circular lines of force concentric with the wire.

If such a length of wire is wound into a coil, as in Fig. 8(b), it becomes a solenoid. The fields of adjacent windings combine and a magnetic field is formed along the axis of the solenoid. The field strength is proportional to the current flowing and to the number of turns in the coil. As stated before, a piece of magnetizable material placed inside the coil becomes magnetized by induction.

The Inverse Square Law

12. The force existing between two poles varies inversely as the square of the distance between them. Generally speaking it is impossible to isolate single poles, and the more practical law covering cases where both poles of a magnet are effective is that the force varies inversely as the CUBE of the distance. A practical expression of this law is as follows :—

$$\frac{\text{New deviation}}{\text{Old deviation}} = \frac{\text{Old distance}^3}{\text{New distance}^3}$$

The above formula is used for determining the amount of deviation which will be caused when a piece of magnetic material is placed at different distances from, say, the needle of an aircraft compass.

Example:—

13. A metal instrument placed 12 inches from an aircraft compass causes a deviation of 5° with the aircraft on a certain heading. To what distance must the instrument be moved so as to reduce the deviation to 1° ?

From the above :—

$$\begin{array}{rcl} \text{Old deviation} & = & 5^\circ \\ \text{New deviation} & = & 1^\circ \\ \text{Old distance} & = & 12 \text{ inches} \end{array}$$

The calculation then becomes :—

$$\begin{aligned} \frac{1^\circ}{5^\circ} &= \frac{12^3}{\text{New distance}^3} \\ \therefore \text{New distance} &= \sqrt[3]{5 \times 12^3} \text{ inches.} \\ &= 20.5 \text{ inches.} \end{aligned}$$

The Moment of a Magnet

14. The moment of a magnet is the most important characteristic of the magnet and corresponds, say, to the horse power of an engine. It is, briefly, the power of the magnet. Before it can be properly defined, two other elementary definitions are necessary :

(i) Unit Pole :

When two exactly similar poles, placed 1 cm. apart, exert on each other a force equal to 1 dyne,* each is said to be a unit pole.

(ii) Unit Field :

When a unit pole, placed in a magnetic field, is acted upon by a force equal to 1 dyne, unit field is said to exist at that point.

15. The moment of a magnet may be defined as follows :—

"The moment of a magnet is equal to the moment of the couple necessary to maintain it at right angles to a magnetic field of unit intensity."

From this it can be seen that the greater the pole strength and the greater the length of a magnet the greater will be its tendency to turn into line with a surrounding magnetic field. Conversely, the greater will be the power it exerts upon the surrounding field or, indeed, upon any magnetic material in its vicinity.

It is therefore evident that the moment of a magnet (usually expressed in c.g.s. units) is an indication of the strength of the magnetic influence it can exert.

* A dyne is the force required to produce an acceleration of 1 cm. per second, per second in a mass of 1 gramme.

Magnetic Shielding

16. A space which is shielded by a shell of "soft" magnetic metal contains only a small percentage of the lines of force of an external magnetic field which would otherwise be present. Most of the lines of force are directed to, and pass along the body of the "soft" shield. Therefore the directive force of the earth's magnetic field will be greatly reduced in an aircraft where there is much protective armour plate.

TERRESTRIAL MAGNETISM

General

17. The surface of the Earth is covered by a weak magnetic field which culminates in two internal Magnetic Poles, situated near the North and South Geographic Poles. The North Magnetic Pole is "blue" in character, and the South Magnetic Pole is "red."

The Earth's magnetic field differs from that of an ordinary magnet in several respects. Its points of maximum intensity or strength are not at the Magnetic Poles, but occur at four other positions, two near each pole, known as magnetic foci. The Magnetic poles themselves are continually changing their positions. Moreover, the field is not symmetrical and is continually varying its direction relative to the True meridians.

The Principle of the Magnetic Compass

18. A freely-suspended magnetic needle will align itself with the Earth's field, red end to the North, if undisturbed by other magnetic influences. (See paragraph 22.) The line on the Earth's surface which is parallel to the needle is known as the Magnetic Meridian at the point in question.

Since at any point the angle (known as *Variation*) between the Magnetic Meridian and the True Meridian can be measured, and its changes accurately predicted, the freely-suspended magnetic needle can be used as a datum from which to measure direction on the Earth's surface.

The Earth's lines of magnetic force are vertical to the surface at the Magnetic Poles and parallel to the surface midway between them. A freely-suspended magnetic needle, on a journey from one Magnetic Pole to the other, would therefore commence by being vertical to the Earth's surface and then pass through decreasing angles of depression until it became horizontal. Its angle of depression would then gradually increase until the needle was vertical once more. The angle such a needle makes with the horizontal at any given point on the Earth's surface is known as *Magnetic Dip*.

The magnet system of a compass is so balanced on its pivot that it always remains practically horizontal and is affected only by the horizontal component of the Earth's magnetic force. It is thus more suitable for indicating direction than a freely-suspended needle lying inclined at the local angle of Dip. Whenever, therefore, the Earth's magnetic field has an appreciable horizontal component, a magnetic compass will function satisfactorily.

Terrestrial Limitations of the Magnetic Compass

19. The unsymmetrical line round the Earth along which Magnetic Dip is zero (i.e., where the lines of force of the Earth's magnetic field are horizontal) is known as the *Magnetic Equator*. It coincides very roughly with the Geographic Equator. At all other points on the Earth's surface the line of total terrestrial magnetic force has a Dip depending on the proximity of each point to the Magnetic Poles.

Wherever Dip exists, the line of total terrestrial magnetic force can be analysed into two components, one horizontal and the other vertical, known as H and Z respectively. (See Figure 12.)

The strength of the horizontal component varies with the *cosine* of the Dip, being at a maximum along the Magnetic Equator (Dip nil), decreasing towards the Magnetic Poles and disappearing altogether directly over them (Dip 90°). Since a magnetic compass depends solely upon the horizontal component for its directional properties, it will obviously cease to operate over the Magnetic Poles and will be extremely sluggish in their immediate vicinity.

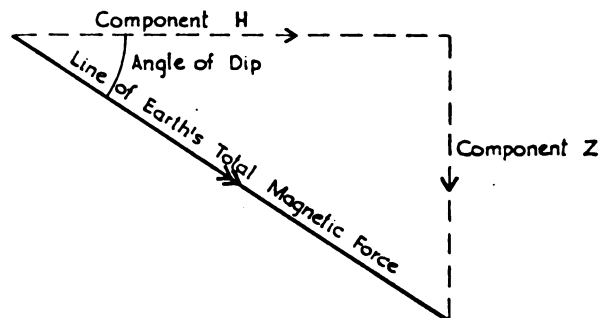


FIGURE 12. The Components Comprising the Earth's Magnetic Force.

Generally speaking, the magnetic compass of an aircraft becomes unreliable where the Dip exceeds 75° . It will operate at its best in the vicinity of the Magnetic Equator.

Variation

20. Variation has been referred to in the preceding paragraphs as the angle between the True and Magnetic meridians at any point. It is named *Westerly* when the red end of the compass needle lies to the West of the True Meridian, and *Easterly* when the red end of the compass needle lies to the East of the True meridian.

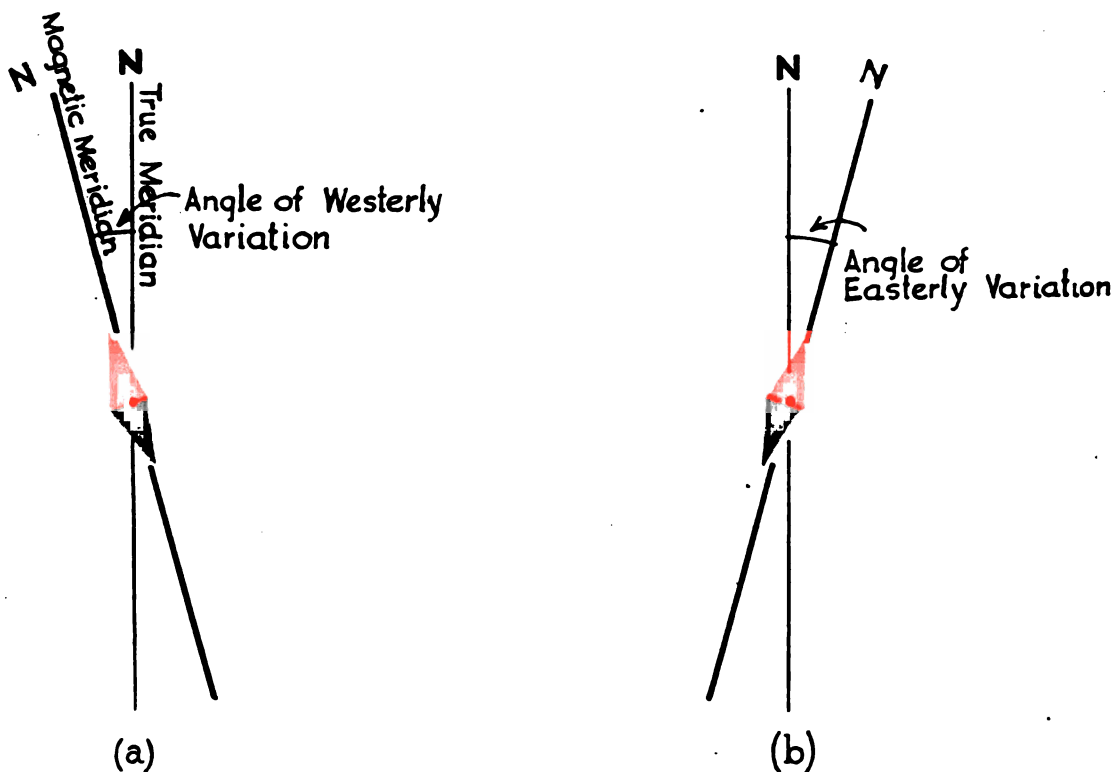


FIGURE 13. Variation.

Its accurate measurement and prediction is of great importance since it forms an essential step between the indications of the magnetic compass and the calculations of the Navigator. Numerous observatories have been set up all over the World, to measure Variation and predict its slow changes. Special magnetic survey ships, built mainly of wood, are used for carrying out the work at sea.

Variation is plotted on maps and charts in the form of *Isogonals*, which are lines joining points of equal Variation. It is also recorded on the compass roses of maps with a statement of its annual change of magnitude.

An isogonal chart of the World is shown in Figure 36.

Dip and Horizontal Force

21. Other work carried out by the observatories and survey ships includes the plotting of Horizontal Force and Dip. The latter is plotted on special charts in the form of *Isoclinals*, which are lines joining points of equal Dip. Isoclinals conform very roughly to the Geographic Parallels of Latitude. Because of this, the term *Magnetic Latitude* is sometimes used instead of Dip.

Charts of the World, showing isoclinals and the distribution of horizontal force, are given in Figures 37 and 38.

The Magnetic Compass

22. The magnetic compass has survived through the ages as an indispensable and universal aid to Navigation because nothing better has yet been devised to take its place. It is a simple instrument to construct, easy to maintain and robust in operation; but, before it can serve its purpose, which is to provide an accurate indication of True North, certain limitations must be taken into account.

The compass needle (a term which includes all types of compass magnet systems) *if affected only by the Earth's magnetic field*, will lie along the local magnetic meridian with its red end indicating local Magnetic North. Under these circumstances, the only correction to be applied to obtain True North is the local Variation, the Navigator merely applying this as requisite.

Unfortunately, however, aircraft compasses are seldom so ideally situated. Modern aircraft are full of metal components, some permanently magnetized during construction, some temporarily magnetized during flight, and others in which the magnetism changes with movements of the aircraft. So the compass needle, even though positioned as far as possible from such components, is nearly always affected by them and deflected from the Magnetic meridian.

This angle of deflection is known as the *Deviation* of the compass, and is named + (or East) when the red end of the needle lies to the East of the Magnetic meridian, and - (or West) when the red end of the needle lies to the West of the Magnetic meridian.

Where Deviation exists, the red end of the compass needle will indicate what is known as Compass North.

The Application of Deviation and Variation

23. The terms "Compass," "Magnetic" or "True" are used to prefix all directions (bearings, Courses and tracks) to indicate whether they have been measured from Compass, Magnetic or True North respectively.

All Compass directions may be converted to their equivalent Magnetic directions by applying the Deviation to which the compass needle is subject at that time. *The sign + or - in front of the Deviation indicates how it must be applied to Compass directions to obtain Magnetic directions.* In other words, Deviation is a correction to a compass reading.

The Magnetic directions may be converted to True directions by applying the local Variation to the former, adding if Easterly, subtracting if Westerly.

Conversion of True directions to Magnetic directions, and Magnetic directions to Compass directions can be done with equal ease, remembering that Variation and Deviation must be applied in the *opposite* way to that stated above.

Examples :—

24. (i) The Compass bearing of a distant object is 219° . Local Variation is 11° W. Deviation of the compass is $+4^\circ$ (E).

What is (a) the Magnetic bearing, and (b) the True bearing?

Compass bearing	=	219°	
Deviation (E)	=	$+4^\circ$	... "Compass Least"
(a) Magnetic bearing	=	223°	
Variation (W)	=	-11°	... "Magnetic Best"
(b) True bearing	=	212°	

(ii) The True Course of an aircraft is 138° .

Local Variation is 12° E. Deviation of the compass is -4° (W).

What is (a) the Magnetic Course, and (b) the Compass Course?

True Course	=	138°	
Variation (E)	=	-12°	... "Magnetic Least"
(a) Magnetic Course	=	126°	
Deviation (W)	=	$+4^\circ$	... "Compass Best"
(b) Compass Course	=	130°	

The Elimination of Deviation

25. Deviation, as has been explained, is an error of the compass indication brought about by local magnetic effects in the aircraft. It can be minimized by neutralizing the resident components of aircraft magnetism. Beyond this, nothing further can be done and Deviation due to transient causes such as sub-permanent magnetism, varying bomb loads and changes in armament must be determined by the Navigator when possible and allowed for in his calculations.

If it is required to neutralize the effect of a certain magnet, the easiest way is to place another magnet of equal strength but opposite polarity adjacent to it: the red pole of one will exactly oppose the effect of the blue pole of the other. This is the principle employed in aircraft to neutralize unwanted permanent magnetism and certain "soft" iron effects inseparable from it.

Analysis of Aircraft Magnetism

26. The permanent magnetism is mostly induced during construction by the Earth's field. The fuselage during assembly receives a large amount of hammering, especially if much riveting takes place, and since it remains stationary in the workshop for the majority of the time, the continual hammering will help the molecules of the metal in their tendency to align themselves with the Earth's magnetic field. They will, in fact, be slowly jolted into alignment. Thus, any metal of the "hard" variety in the fuselage will become permanently magnetized with a polarity depending on the heading of the fuselage during assembly. That half of the fuselage nearest to local Magnetic North will contain the red pole, and that nearest to local Magnetic South the blue pole.

Since the Earth's magnetic field in this country has an angle of Dip of about 67° , fuselages built here will be magnetized permanently in the vertical plane as well as the horizontal.

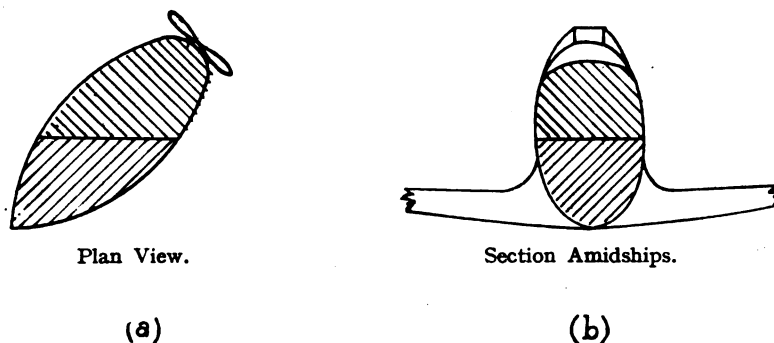


FIGURE 14. Magnetized Fuselage.

In the case of a fuselage built heading NE in this country, the permanent magnetization will appear as in Figure 14 (a) and (b).

27. During normal flight the aircraft and the compass needle are both horizontal. Therefore, except in special circumstances, it is necessary to consider only that part of the permanent magnetism in the aircraft which is horizontal in effect. (See Figure 14 (a).)

If an attempt were made to neutralize the effect as it is, by placing a magnet with opposite polarity *diagonally* across the aircraft, considerable difficulty would be experienced in determining at just what angle the magnet was to be placed and what strength of magnet was to be employed.

So, to simplify correction, the aircraft's diagonal magnetism is analysed into two component parts, one fore-and-aft and the other athwartships. The precise effect of each of these components can easily

be measured in the form of compass Deviation ; neutralizing magnets (usually called *corrector magnets*) of the required strength can then be placed fore-and-aft and athwartships as required. For convenience, the horizontal fore-and-aft component of the aircraft's permanent magnetism is known as P, and the horizontal athwartships component Q. (See Figure 15.) The vertical component only considered in certain cases, is known as R.

Vertical "soft" iron in aircraft, magnetized by the Earth's field, can have the same effects upon the compass as components P and Q, and will act with the latter in their respective fore-and-aft and thwartships planes.

28. Component P and its allied "soft" iron can be represented by a single magnet of similar strength and polarity lying fore-and-aft. In the aircraft referred to above, this magnet would lie with its red end forward and blue end aft. Its effect upon the magnetic compass needle can best be understood with reference to Figure 16 (a).

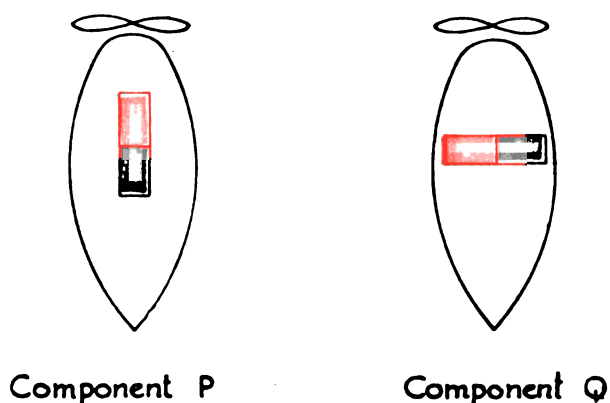


FIGURE 15. Horizontal Components P and Q.

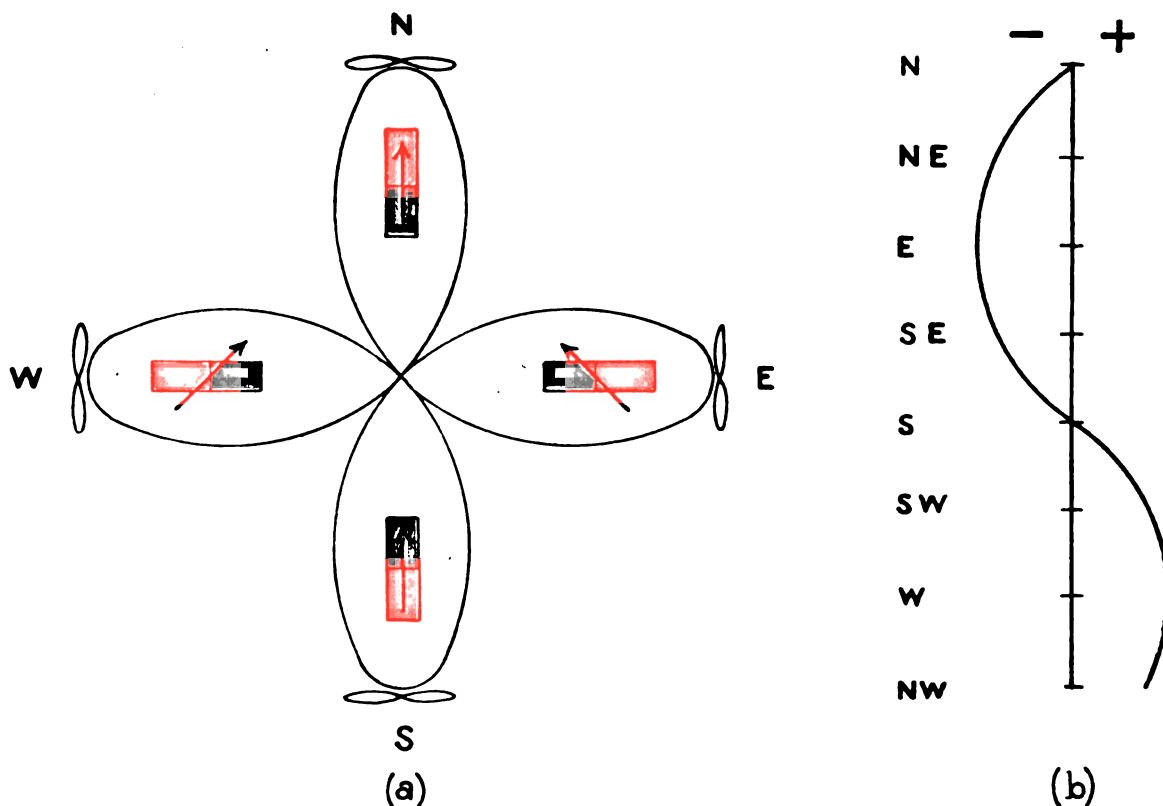


FIGURE 16. Typical Effect of P and Allied "Soft" Iron.

The maximum Deviation will be caused when the fore-and-aft magnet is at right-angles to the compass needle. This occurs when the aircraft is heading East or West by compass, the sign of Deviation on East being opposite to that on West. In the case under consideration, the signs will be - and +

respectively. Zero Deviation will occur when the aircraft is heading North or South by compass, in which positions the fore-and-aft magnet is in line with the compass needle. Intermediate amounts of Deviation occur at other headings.

An appropriate curve showing changes of Deviation due to P with changes of compass heading is given in figure 16 (b). If drawn accurately it would be a *sine* curve.

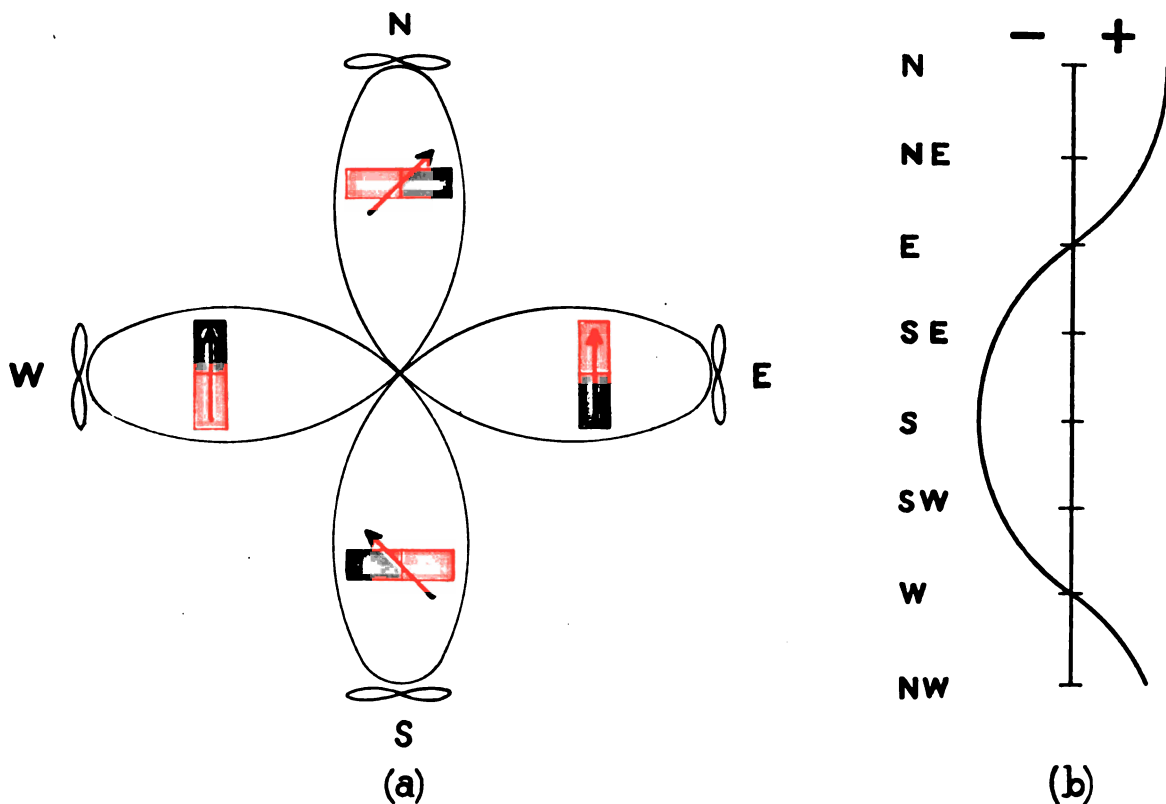


FIGURE 17. Typical Effect of Q and its Allied "Soft" Iron.

29. Similar treatment of Q and its allied "soft" iron in the aircraft under consideration gives the diagram and *cosine* curve in Figure 17 (a) and (b).

Maximum Deviation due to this cause occurs on the North and South compass headings, the sign of Deviation on North being opposite to that on South. In the case under consideration, the signs will be + and - respectively.

Coefficients B and C

30. Coefficients B and C are the calculated quantities of Deviation due to P and Q respectively. (Vertical "soft" iron effects are included.)

Coefficient B is the algebraic value of the Deviation produced by component P and its allied vertical "soft" iron when the aircraft is heading Magnetic East. It is calculated by the following formula :—

$$B = \frac{(\text{Deviation on Magnetic East} - \text{Deviation on Magnetic West})}{2}$$

Example :—

31. When swinging an aircraft, the following Deviations were determined :

Deviation on Magnetic East = + 3°

Deviation on Magnetic West = - 5°

$$\therefore \text{Coefficient B} = \frac{+ 3^\circ - (-5^\circ)}{2} = \frac{+ 3^\circ + 5^\circ}{2} = + 4^\circ.$$

Coefficient C is the algebraic value of the Deviation produced by component Q and its allied vertical "soft" iron, when the aircraft is heading Magnetic North. It is calculated by the following formula :—

$$C = \frac{(\text{Deviation on Magnetic North} - \text{Deviation on Magnetic South})}{2}$$

Example :—

32. The following Deviations were found when swinging an aircraft :

Deviation on Magnetic North = -2°

Deviation on Magnetic South = $+4^\circ$

$$\therefore \text{Coefficient C} = \frac{-2^\circ - (+4^\circ)}{2} = \frac{-2^\circ - 4^\circ}{2} = -3^\circ.$$

Coefficient A

33. An aircraft compass, when installed correctly, has its lubber line (the mark which represents the aircraft's head and against which Courses are read) exactly in the fore-and-aft line passing through the compass position. If, however, the lubber line is displaced, all Courses read against it will have an error equal to the number of degrees by which it is out of alignment. For example, if the lubber line be displaced 3° to Starboard of the fore-and-aft line, all Courses read will be 3° too great. If a Course of 048° is indicated, the correct heading would be 045° and so on. The compass would, under these circumstances, have an apparent Deviation, *constant on all headings*, of -3° .

Certain arrangements of horizontal "soft" iron can also produce a constant Deviation indistinguishable from the mechanical kind referred to above. It is seldom of any appreciable value.

Constant Deviation, two causes of which are given above, is known as coefficient A.

To eliminate coefficient A it is necessary merely to rotate the whole compass until the lubber line is correctly positioned. It is calculated by the following formula :—

$$A = \frac{(\text{Deviations on Magnetic N} + \text{NE} + \text{E} + \text{SE} + \text{S} + \text{SW} + \text{W} + \text{NW})}{8}$$

Example :—

34. The following Deviations were found when swinging an aircraft :

Magnetic Heading	Compass Deviation
N	-1°
NE	-3°
E	-5°
SE	-2°
S	0°
SW	$+1^\circ$
W	$+2^\circ$
NW	0°

$$\text{Coefficient A} = \frac{-1^\circ - 3^\circ - 5^\circ - 2^\circ + 1^\circ + 2^\circ}{8} = \frac{-8^\circ}{8} = -1^\circ$$

Coefficients D and E

35. These coefficients are caused by horizontal "soft" iron magnetism.

D is sometimes appreciable in aircraft, being the value on Magnetic North-East of the Deviation due to symmetrical horizontal "soft" iron. This Deviation is maximum on NE, SE, SW and NW, being zero on the cardinal headings and changing its sign every 90° . Correction for Coefficient D, although not often made, can be effected by the introduction of soft iron spherical correctors placed about the compass position. Correction for Coefficient E may be made in the same manner.

Swinging an Aircraft for Compass Adjustment

36. The purpose of swinging an aircraft is two-fold. First, it is to neutralize as much of the aircraft's magnetism as possible and thereby to provide the compass with a position in which it can operate to the best advantage. Second, it is to tabulate for the information of the Navigator any Deviations remaining after the coefficients A, B and C have been eliminated.

For accurate and reliable results, aircraft should be swung under the conditions in which the compass is normally used, namely, in cruising flight. When this is not possible, aircraft must be swung on the ground.

Swinging, combined with the simple maintenance schedule described in paragraph 83, should be carried out at the times specified in K.R. and A.C.I., para. 762. This will ensure the best possible service from compasses at all times.

37. The elimination of coefficients B and C is brought about by the introduction of magnetic fields at the compass position of such strength and polarity that they exactly neutralize components P and Q and their allied components (due to vertical "soft" iron). These neutralizing magnetic fields are produced by either of two devices.

(i) The first of these devices is obsolescent and consists of a block of wood secured beneath the compass. In this block are a number of holes, some drilled fore-and-aft and others athwartships. Small magnets are inserted in the fore-and-aft holes until coefficient B is eliminated, and in the athwartships holes until C is eliminated.

(ii) The second device, in general use throughout the Royal Air Force and sometimes known as the micro-adjuster, consists of a circular metal box secured beneath the compass. Inside the metal box are two pairs of magnets, one pair lying fore-and-aft and the other athwartships. When neutral, the magnets in each pair lie parallel, with opposite poles adjacent. If a magnetic field is required to neutralize P or Q, the appropriate pair of magnets is opened scissorwise by gearing, until it forms a cross. This is achieved by means of a special key inserted and turned in either of two external control heads. The opening of the magnets causes a magnetic field to be released for neutralizing purposes. The further the magnets are opened, the stronger the field becomes.

There are four external control heads, two diametrically opposite for each pair of magnets. It should be remembered that the key must always be used in either of the two control heads whose common axis lies at *right-angles* to that of the compass needle at the time.

38. To compute the necessary compass Deviations, the magnetic headings of the aircraft, obtained from external sources, are compared with the respective compass headings. The magnetic headings may be obtained in either of two ways.

(i) If using a compass base, the aircraft can be aligned on the compass base lines as requisite. It is as well to ensure that the base has been calibrated within the last 4 years. The last date of calibration should be found painted on it.

(ii) If a compass base cannot be used, the best method is to place a landing compass, or a convenient type of bearing compass, accurately ahead or astern of the aircraft and not less than 30 yards from it. A bearing along the centre line of the aircraft will then give its magnetic heading. Care must be taken to keep the compass used well away from any local disturbing magnetic influence.

39. When reading the compass in the aircraft, care must be taken to keep the eye vertically above the centre of the compass in question. Considerable reading errors due to parallax will occur if this is not done owing to the fact that the aircraft is usually 10° – 15° tail down, and the compass graduations accordingly inclined to the compass needle.

If accurate results are to be obtained, compass adjustment must never be rushed. Compasses must be given plenty of time to settle down on each heading. Slight tapping of the compass will be found to assist this. Corrections, if carried out, must be done carefully and with patience; slight tapping of the compass will again aid the process.

The use of engines during swinging on the ground is optional. Since they cannot be run continuously at cruising r.p.m. to simulate actual flying conditions, there is no object in using them except for manœuvring.

Procedure for Swinging

40. The process of swinging is divided into three distinct phases. The first of these is the *correcting swing*, during which coefficients B and C are computed and eliminated with whatever corrector device is fitted. The second is the *check swing*, the object of which is to determine what Deviations remain. The third is the computation and removal of coefficient A and the recording of residual Deviations for the information of the Navigator.

41. Before carrying out a swing, the following preparation is necessary:—

- (i) Check the compass for serviceability as described in paragraph 83.
- (ii) Remove from the aircraft any magnetic objects not normally carried in flight and liable to affect the compass. Ensure that no magnetic objects, liable to affect the compass, are carried by those engaged on the swing.

(iii) See that magnetic equipment, normally carried in flight and likely to affect the compass, is in position as far as possible. The flying controls, if near the compass, should be kept in level-flying position throughout the swing.

(iv) Take the aircraft to a compass base or some other level site removed from local magnetic disturbance.

42. On arrival at the selected site the swing may be carried out by the method given below. The aircraft's head must be within 5° of the magnetic heading detailed.

The Coefficient Method

First Phase

(a) Place the aircraft's head on magnetic North and note the Deviation.

(b) Place the aircraft's head on magnetic East and note the Deviation.

(c) Place the aircraft's head on magnetic South and note the Deviation. Calculate coefficient C and correct it in the following manner :—

Change the sign of C (since the aircraft is now heading South) and add it algebraically to the compass reading. This figure will be what the compass must read after correction. Now use the corrector device to make the compass read this figure. To do this with the micro-adjuster, insert the special key in one of the two control heads whose common axis lies at right-angles to the compass needle (in this case the port and starboard control heads) and turn gently in the appropriate direction until the required reading is obtained. Then remove the key. If using a corrector box, insert magnets athwartships until the required reading is obtained.

Example :—The compass of an aircraft reads 358° when the aircraft heading is 000° M. The Deviation is therefore + 2°. When heading 180° M, the compass reads 182°. The Deviation is therefore - 2°.

$$\begin{aligned}\text{Coefficient C} &= \frac{(\text{Deviation on N} - \text{Deviation on S})}{2} \\ &= \frac{(2^\circ - (-2^\circ))}{2} = \frac{+4^\circ}{2} = +2^\circ.\end{aligned}$$

While the aircraft is on Magnetic South, the coefficient C of + 2° will be eliminated if the compass is made to read 182° - (+ 2°), namely, 180°.

(d) Place the aircraft's head on magnetic West and note the Deviation. Calculate coefficient B and correct it as for coefficient C, as follows :—

Change the sign of B (since the aircraft is now heading West) and add it algebraically to the compass reading. This figure will be what the compass must read after correction. Then use the corrector device to make the compass read this figure. To do this with the micro-adjuster, insert the special key in one of the two control heads whose common axis now lies at right-angles to the compass needle (in this case the fore-and-aft control heads) and turn gently in the appropriate direction until the required reading is obtained. Then remove the key. If using a corrector box, insert magnets fore-and-aft until the required reading is obtained.

Example :—The compass of an aircraft reads 093° when the aircraft heading is 090° M. The Deviation on East is therefore - 3°. When heading 270° the compass reads 267°. The Deviation on West is therefore + 3°.

$$\begin{aligned}\text{Coefficient B} &= \frac{(\text{Deviation on E} - \text{Deviation on W})}{2} \\ &= \frac{(-3^\circ - (+3^\circ))}{2} = \frac{-6^\circ}{2} = -3^\circ.\end{aligned}$$

While the aircraft is on magnetic West, the coefficient B of - 3° will be eliminated if the compass is made to read 267° - (- 3°), namely, 270°.

Second Phase

Conduct a check swing by placing the aircraft's head successively on the eight Cardinal and Quadrantal Points, and note the deviation on each.

Third Phase

(a) From these eight deviations, calculate coefficient A. Loosen the compass fixing screws, and remove A by rotating the whole compass that number of degrees in the appropriate direction (clockwise if A is +, and vice-versa). Re-tighten the screws.

Coefficient A should be corrected only if of the order of 1½° or more, and then only on the authority of the responsible navigation officer.

- (b) Prepare and fit in the aircraft a Deviation Card of the remaining Deviations (*see* paragraph 44).
 (c) Fill in the Compass Log Book.

A suitable *pro-forma* is given below in the example of a swing by the Coefficient Method.

Example :—

43. A Manchester aircraft is swung on the ground on April 1st, 1941. The following filled-in *pro-forma* shows the results of the first two Phases, as described in paragraph 42 (ii) for the stand-by compass.

After the Check Swing and the removal of coefficient A, the residual Deviations are found as tabulated in the bottom right-hand column of the *pro-forma*.

Date : 1/4/41		Aircraft Type and No. : Manchester X.2341			
		Compass Type and No. : P.4 521.D.			
CORRECTING SWING					
(i) Approx. Course (M)	(ii) Actual Course (M)	(iii) Aircraft Compass reads	(iv) Deviation (ii)–(iii)	Coefficients	
NORTH	359	003	– 4	$C = \frac{\text{Dev. on N} - \text{Dev. on S}}{2}$ $= \frac{-4 - 8}{2} = -6$	
EAST	091	085	+ 6		
SOUTH	178	170	+ 8		
C (sign changed)		+ 6			
Make Compass read		176			
WEST	267	265	+ 2	$B = \frac{\text{Dev. on E} - \text{Dev. on W.}}{2}$ $= \frac{+6 - 2}{2} = +2$	
B (sign changed)		– 2			
Make Compass read		263			
CHECK SWING					
(i) Approx. Course (M)	(ii) Actual Course (M)	(iii) Aircraft Compass reads	(iv) Deviation (ii)–(iii)	(v) Coefficient A	(vi) Residual Deviations (iv)–(v)
N.W.	317	316	+ 1	+ 3	– 2
NORTH	000	358	+ 2	+ 3	– 1
N.E.	047	042	+ 5	+ 3	+ 2
EAST	093	089	+ 4	+ 3	+ 1
S.E.	135	134	+ 1	+ 3	– 2
SOUTH	179	177	+ 2	+ 3	– 1
S.W.	225	220	+ 5	+ 3	+ 2
WEST	273	269	+ 4	+ 3	+ 1
Total :			+ 24 ÷ 8 =		+ 3

Recording Deviation

44. The remaining Deviations referred to in *Third Phase (b)* above must be recorded for use in the air. For this purpose, *Deviation Cards* are provided for the use of the Pilot and the Navigator. They are placed in their appropriate holders near the compass position to which they refer. Owing to the difficulty of applying the correct Deviation in flight, many Navigators keep a copy of the Deviation Card applicable to the Pilot's compass so that the Pilot only has to deal with Compass Courses during flight.

45. In practical Air Navigation, Deviation is always taken to the nearest degree. Thus, if the Deviation were $+1.3^\circ$, the value used would be $+1^\circ$, and so on. It follows that the *headings* where the Deviation has a value containing $\frac{1}{2}^\circ$ are in effect *critical points*, since on either side of them the Deviation is in practice one complete degree different. These critical headings are determined by drawing a graph of the residual Deviations in the space provided in the Compass Log Book (Form 343) and noting at what headings the graph cuts the half-degree lines.

46. By recording the critical headings and the Deviations that are applicable between them, the Pilot and Navigator are presented with Deviations in the simplest possible form. The Deviation Cards provided in the Royal Air Force are pictorial critical tables and require the minimum of effort to use.

47. Having made out the graph of the residual Deviations in the Compass Log Book (see Figure 18), the compass adjuster should take the Deviation Card, and insert the value of the Deviations against the appropriate Magnetic headings.

He should then draw four lines, radiating like spokes, to the headings, where the sign of the Deviation changes from positive to negative. The Card will then be divided into segments, and the word "Add" should be plainly marked in the segments where Deviation is minus, and the word "Subtract" in the segments where Deviation is plus. Thereafter the Deviation for any heading is obvious from the Card at first glance. The particulars on the reverse side of the Form should then be completed, and the Card inserted in its proper holder. In this manner, the use of plus and minus signs is deliberately avoided in order to save any ambiguity.

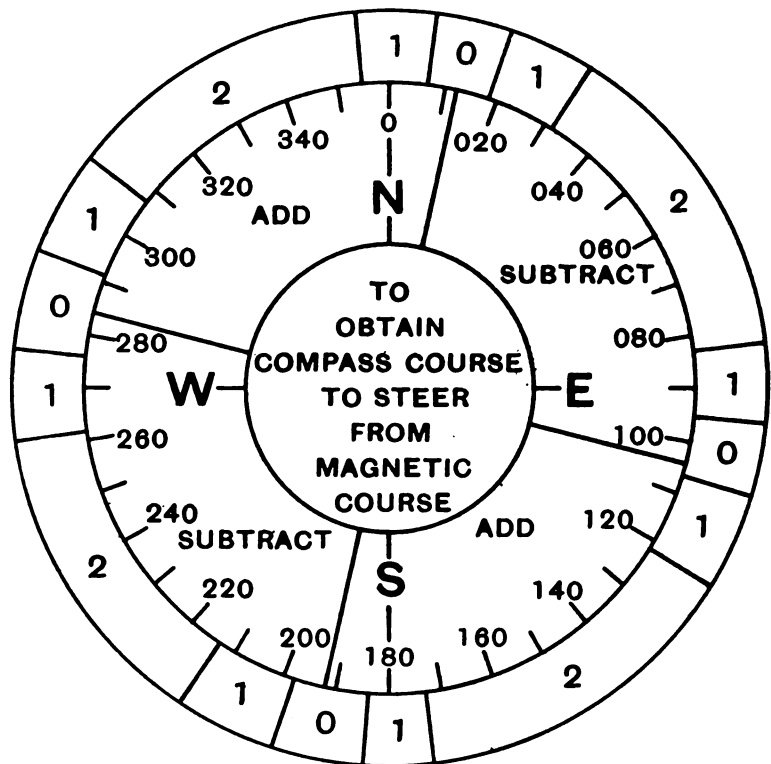
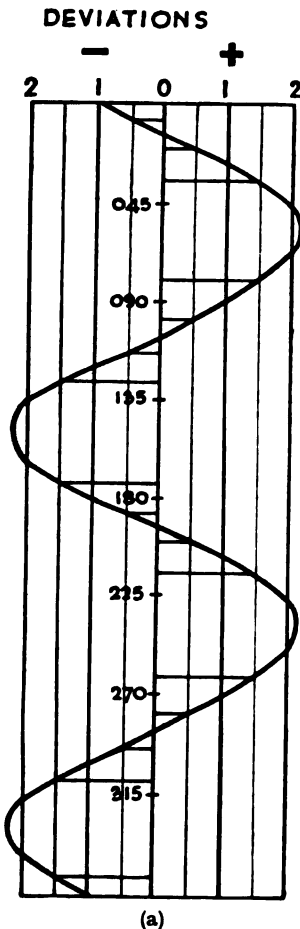


FIGURE 18. Recording Deviations.

Some Practical Aspects of Swinging

48. It frequently occurs, especially in the case of flying boats, that the only place available for swinging an aircraft is between or near hangars or in the vicinity of other objects likely to affect the direction of the Earth's magnetic field. If the distortion of the field is constant over the whole area utilised for the swing (including landing compass positions, if used), the swing will be just as satisfactory as when carried out in more favourable positions. It is, however, always inadvisable to swing aircraft inside hangars, over large masses of metal or in other places where the magnetisation of the aircraft's "soft" iron is likely to be affected.

49. A method of determining whether a doubtful site is satisfactory is as follows: Select some clearly visible object 3-4 miles distant, so that its bearing is, for practical purposes, the same at all extremities of the area, which, of course, need not be very extensive. Using a landing compass or other suitable bearing compass, take compass bearings of the object from various points on the site, including the extremities. If these bearings agree to within 1° of each other the site will be satisfactory.

50. If the direction of the Earth's field is found to vary over the area, *i.e.*, if the compass bearings referred to in paragraphs 49 do *not* agree, it may still be used, provided that the aircraft is swung in one spot around an imaginary axis passing vertically through the compass, and that the landing compass method of swinging is not employed. The following procedure should be adopted:—

(i) Before the swing, use some convenient form of bearing compass to measure the magnetic bearing of a distant object from the position that will be occupied by the aircraft compass during the swing.

(ii) Put the aircraft on the approximate required heading by means of the Pilot's compass. Measure the *relative* bearing (0° — 360°) of the distant object from the aircraft's head, by means of an O.2 compass, a Bearing Plate, or a Marine-type sextant.

(iii) Obtain the Magnetic heading of the aircraft from the formula:
 Magnetic Heading = Magnetic Bearing of Object + $(360^\circ - \text{Relative Bearing})$, — 360° if necessary.

(iv) Compare the compass Course of the aircraft with the magnetic heading, (iii). Any difference will be the amount of Deviation of the compass on that heading. Its sign will be " + " if the compass Course is *less* than the magnetic heading, (iii), and vice versa.

(v) Repeat the process as necessary for the completion of the swing.

For a quick method of obtaining the magnetic heading of the aircraft, an Astro-compass may be employed as described in paragraph 94. This instrument avoids the calculations necessary when relative bearings are used.

Swinging of Aircraft Afloat

51. Compasses should never be corrected when the aircraft is afloat owing to the difficulty of keeping the heading steady. It may occasionally be necessary, however, to carry out a check swing on the water. Calm water and no appreciable wind are essential.

52. The main problem is to determine the correct magnetic heading of the aircraft at a given moment. The Astro-compass is the best instrument for this purpose. If the Sun is visible, the True headings of the aircraft may be found in the manner described in paragraph 89 (i). The required Magnetic headings are obtained by applying the local Variation. Should the Sun be obscured, a distant object whose Magnetic bearing is known can be used as described in paragraph 49 above.

53. Whether using the Sun or a distant object the procedure would be as follows:—

(i) Steady the aircraft approximately on the heading required. When absolutely steady, note the Course indicated by the Astro-compass and aircraft compass simultaneously. Two observers with some signal pre-arranged between them are essential for this. The difference between the two headings will be the Deviation of the compass. When using instruments giving relative bearings of distant objects, note the relative bearing and compass course simultaneously. Thereafter proceed as in paragraph 50 (iii) and (iv).

(ii) Repeat the process on as many headings as practicable throughout the 360° . At least eight headings are essential. If possible the headings should be on the cardinal and quadrantal points.

(iii) A graph of the Deviations obtained should then be constructed, and the necessary information to prepare a Deviation Card extracted from it.

Objections to Swinging on the Ground

54. The Deviations obtained from the swinging of aircraft on the ground will correspond only in very few cases to those obtaining in cruising flight. The main reasons for this are as follows :—

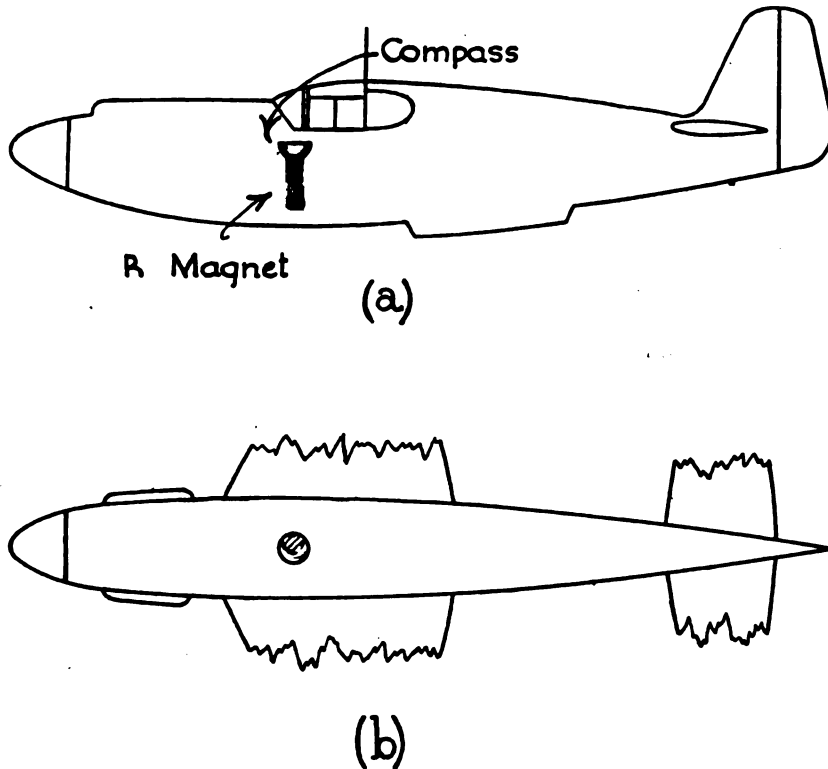


FIGURE 19. Component R, Level Flight.

(i) *Component R*

As has been mentioned elsewhere, component R is the vertical component of the aircraft's permanent magnetism. It can be represented by a single magnet, perpendicular to the plane of the aircraft, and whose axis passes through the centre of the magnet system of the compass. In the case of aircraft built in the Northern magnetic hemisphere, this magnet will have its blue pole uppermost.

When the aircraft is in the level cruising position, R will have no effect upon the compass, as can be understood from Figures 19 (a) and (b).

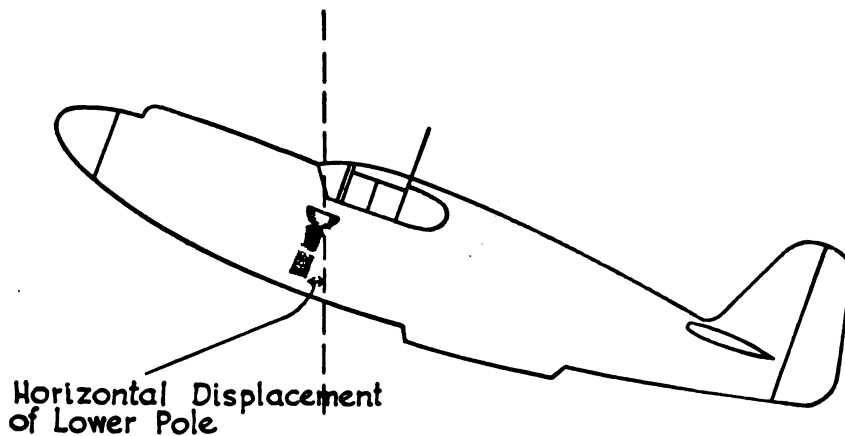


FIGURE 20. Component R, Tail Down.

Normally, however, the aircraft when on the ground will be tail-down by a number of degrees depending upon the type in question. The R magnet will also be tilted from the vertical through the same angle, and its lower pole thereby displaced a small distance *horizontally* from the centre of the compass. (See Figure 20.)

The pole will thus exert a horizontal force upon the compass needle in the fore-and-aft line. The effect on the needle will be similar to that due to component P, Deviation being maximum on East and West, and zero on North and South.

Deviation due to R, non-existent in level flight, will, therefore, be erroneously included in the calculation and subsequent correction of coefficient B.

Note.—It is possible to neutralize component R with vertical permanent magnets. A type of corrector has been designed for this purpose.

(ii) Under-carriage Retraction

The difference in position between an under-carriage when extended and when retracted may change considerably its effect upon the compass.

Since under-carriages are normally extended during swinging on the ground, the Deviations observed during the swing will not apply when the under-carriage is retracted as in flight.

Various systems of jacks and turntables have been suggested to permit aircraft to be swung on the ground in flying position and with under-carriage retracted. In the case of all but very light aircraft, however, such apparatus would have to be too massive and elaborate to be a practical proposition.

55. The use of engines for ground swings is prohibited, as long periods of idling, especially in warm weather, are detrimental to the engines.

In the case of small aircraft, man-handling is sufficient ; but, where aircraft are too big for this it will be necessary to use a tractor. However, since only when in flight are cruising conditions fully represented (engines running, controls correctly positioned, tail in flying attitude), it is recommended that check swings by astro-compass be conducted whenever weather permits, and the aircraft is suitably equipped.

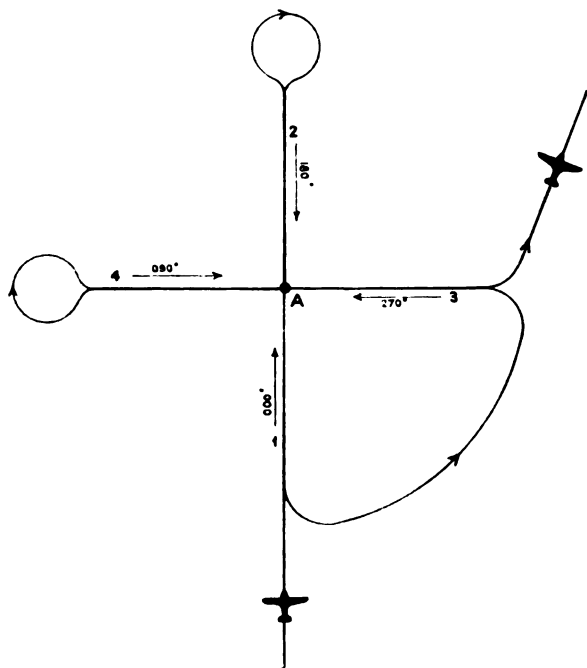


FIGURE 21. Swinging in the Air.

Swinging Aircraft in the Air

56. The disadvantages and inaccuracies of ground swinging are all avoided when the aircraft is swung in flight. With the Astro-compass, described in paragraph 85 *et seq.*, the process is easy and quick.

The practical requirements are :—

- (i) Calm air conditions.
- (ii) A visible Sun whose altitude is preferably less than 45° .
- (iii) Sufficient view of the ground to permit pin - pointing of the aircraft.
- (iv) Positions for the Astro-compass in the aircraft which provide an adequate view of the Sun on all the cardinal and quadrantal Courses.
- (v) A watch keeping G.M.T.
- (vi) One Navigator in addition to the Pilot.
- (vii) Automatic Controls.

Procedure for Swinging in the Air

57. Assuming that it is required to swing the Pilot's compass in a certain aircraft, the following procedure is recommended :—

(i) From the *Air Almanac* prepare a graph of G.M.T. against L.H.A. Sun at a selected position, A, for a period covering that during which the swing is to take place. This graph is simply drawn as a straight line between the values of L.H.A. Sun for the G.M.T.s of the start and finish of the swing.

(ii) Prepare the aircraft for swinging as described in paragraph 41.

(iii) Take off and using automatic controls, fly straight and level at normal cruising speed over point A on a compass Course of 000° (see Figure 21). With the graph of L.H.A. Sun and G.M.T., determine the aircraft's True Course by the method described in paragraph 89 (i). Apply local Variation to obtain the Magnetic Course and thence the Deviation of the Pilot's compass. The mean of a number of Astro-compass readings should be taken.

(iv) Repeat the above procedure on compass Courses of S, E and W, flying according to Figure 21. For greatest saving of time, the Courses should be flown in the order given, e.g. 1, 2, 3 and 4. The Courses shown are Magnetic, and the aircraft should be steered within 5° of them. Keep always within 10 miles of point A.

(v) Land and calculate coefficients B and C.

(vi) Place the aircraft's head on S by compass and remove coefficient C.

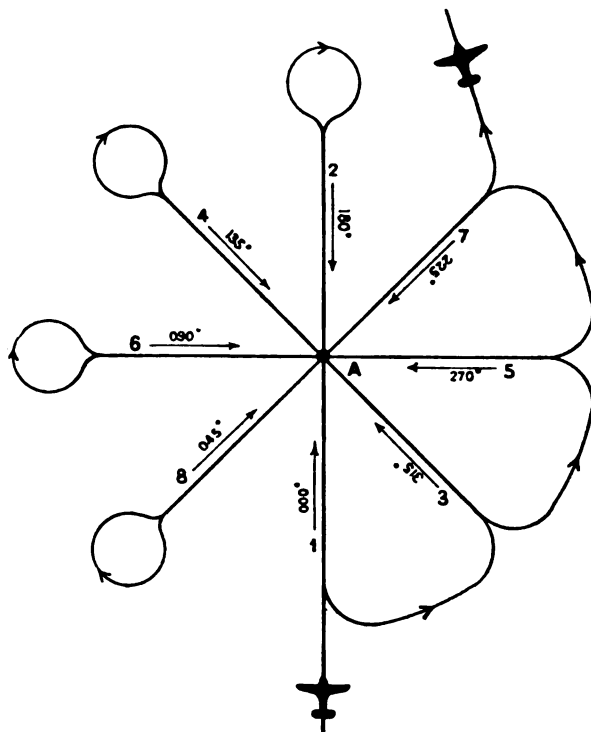


FIGURE 22. Check Swing in the Air.

Example :—

(Coefficient C	= $+ 4^\circ$
Aircraft's head by compass	= 180°
C, with sign changed	= $- 4^\circ$

$\therefore$ make compass read 176° (with micro-adjuster or magnets).

(vii) Place the aircraft's head on W by compass and remove coefficient B.

Example :—

(Coefficient B	= $- 3^\circ$
Aircraft's head by compass	= 270°
B, with sign changed	= $+ 3^\circ$

$\therefore$ make compass read 273° (with micro-adjuster or magnets).

(viii) Take off and, using the Astro-compass as before, carry out a Check Swing on the 8 cardinal and quadrantal compass Courses, flying according to Figure 22. Again, to save time, fly in the order shown, keeping within 5° of the illustrated Magnetic Courses and within 10 miles of point A.

(ix) Land. Calculate and correct for coefficient A. Prepare a Deviation Card and fill in the Compass Log Book in the usual manner.

Note : If time does not permit steps (i)-(iv) above of the Correcting Swing being done in the air, they may be done before flight. The same accuracy of correction, however, cannot always be expected if B and C are calculated from Deviations obtained on the ground.

Change of Deviation during Flight

58. Deviation of the compass may change during flight, and differ from that shown on the Deviation Card owing to any of the following causes :—

- (i) Change of magnetic latitude. (See paragraph 65 (i).)
- (ii) Change of bomb load.
- (iii) Continuous vibration of the aircraft.
- (iv) Continuous operation of electrical circuits.
- (v) Electrical storms encountered.

It is, therefore, essential to check the compass Course during flight as frequently as possible. The Astro-compass should be used to obtain the actual True Course of the aircraft. (See paragraph 89 (i)). If this does not agree with the required True Course, the compass Course being steered should be altered accordingly. The mean of a number of Astro-compass readings should be taken at each check.

Acceleration and Deceleration Errors of the Magnetic Compass

59. These errors, which are transient, are better described as temporary misbehaviours of the compass. They occur during changes of Course and speed, and produce the worst results, from the Pilot's point of view, when turning on northerly Courses in the Northern hemisphere and on southerly Courses in the Southern hemisphere. Their cause and effects form the subject of the ensuing paragraphs.

60. A pendulum suspended in an aircraft will, as long as a constant Course and speed are maintained, remain for practical purposes in the true vertical, with its centre of gravity directly below the pivot or point of suspension. If, however, the aircraft turns, accelerates or decelerates, the pendulum will cease to be vertical. This is because, owing to its inertia, the centre of gravity will lag relative to the pivot and thus move from the normal position vertically below it. In the case of properly-banked turns, the forces acting on its centre of gravity will cause the pendulum to remain *perpendicular to the plane of the aircraft* and to take up an angle to the true vertical equal to the angle of bank.

Since turns themselves are, in effect, accelerations towards their centres and, whether properly-banked, under- or over-banked, always cause a pendulum to take up a false vertical, the subject may be summed up broadly by stating that *any accelerations or decelerations undergone by an aircraft during flight will cause the centre of gravity of a pendulum suspended therein to be deflected from its normal position vertically below the pivot.*

61. The magnet system of a compass, to satisfy its requirements, must operate as nearly horizontal as possible. To achieve this, the vertical component, Z , of the Earth's field must, in the Northern hemisphere, be prevented from pulling the red end of the compass needle downwards towards the North Magnetic Pole, and, in the Southern hemisphere, be prevented from pulling the blue end of the needle downwards towards the South Magnetic Pole.

This is done by pivoting the magnet system at a point symmetrically vertical above its centre of gravity. The system is thus made pendulous, the moment of the couple between the centre of gravity and the pivot being sufficient to reduce the dip of the needle in these latitudes from 67° to 2° .

62. The couple can have its maximum effect only when the centre of gravity is, with the pivot, in the plane of the local magnetic meridian. (The local magnetic meridian is taken as that passing through the pivot.) If, for any reason, the centre of gravity is deflected from the plane of the local magnetic meridian, the couple can no longer have its full effect in opposing the Earth's vertical force, and the red end of the compass needle will be free to dip. *This will result in a rotary movement of the needle.* (See Figure 23.) (In the Southern hemisphere the blue end of the needle will be the one affected.)

63. Since the magnet system of a compass is pendulous, it behaves like a pendulum in an aircraft. Any acceleration or deceleration in flight results in a displacement of the centre of gravity of the system from its position beneath the pivot. As long as both pivot and centre of gravity remain in the plane of the magnetic meridian, the compass needle will merely vary in dip without any rotary movement about its pivot.

If, however, the centre of gravity is displaced in any other direction relative to the pivot, the needle will rotate. The rotation will be greatest for a given angle of displacement when the displacement is in the magnetic East or West direction. (See Figure 23.)

64. Maximum East or West displacement of the centre of gravity is produced by a change of Course on North and South headings, and by a change of speed on East and West headings. An example of each is described for the Northern magnetic hemisphere :—

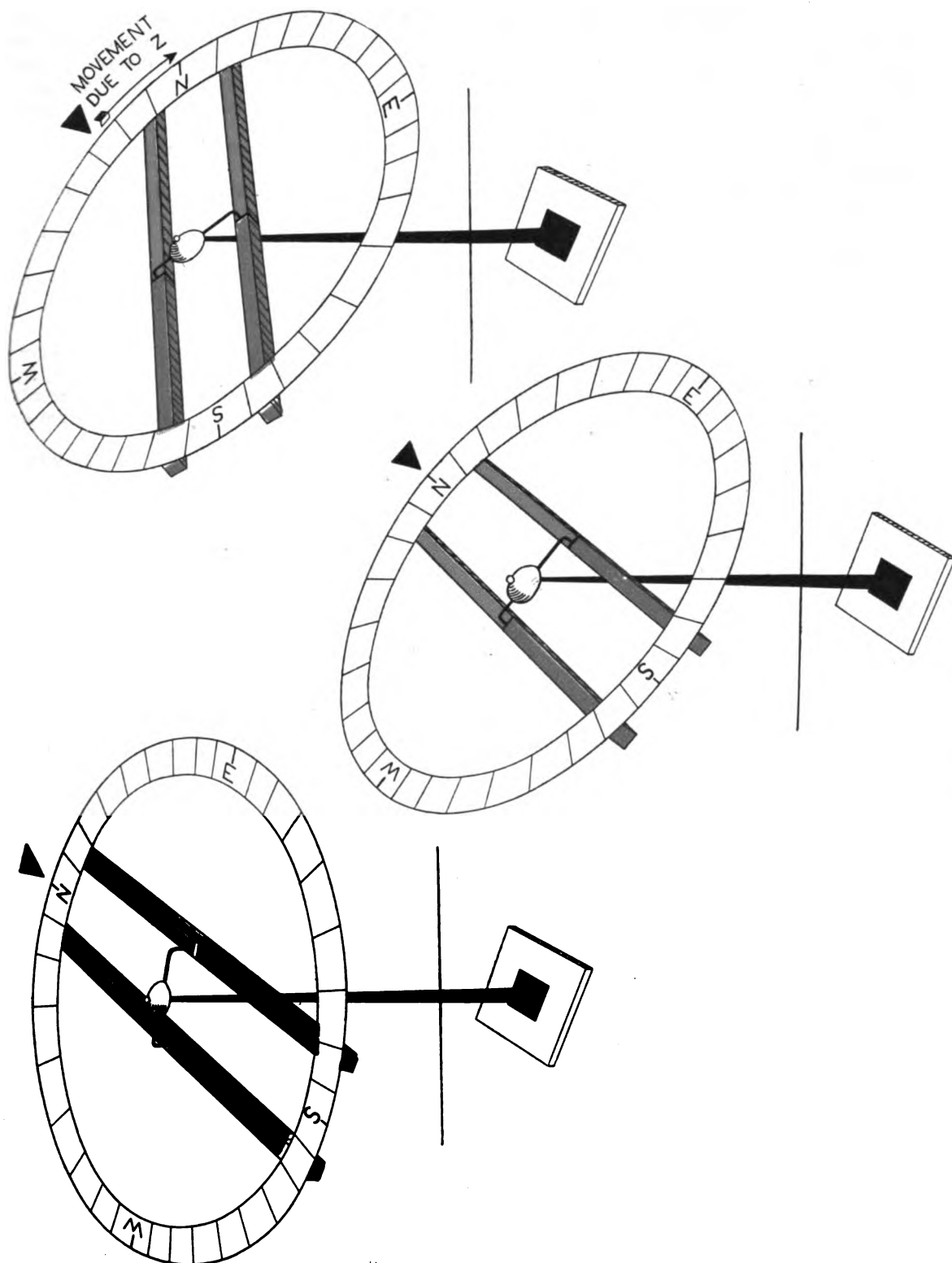


Figure 23. Acceleration and Deceleration Errors

(i) If a properly-banked turn be made from North to East, the magnet system will take up the same angle of bank as the aircraft. The centre of gravity will thus be displaced to the West of the pivot and out of the plane of the local magnetic meridian. More freedom to dip will be permitted, and a rotation of the needle in a clockwise direction will result. (See Figure 23.) The aircraft is also turning clockwise, so that, if both it and the needle are rotating at the same angular speed, the compass will not indicate any turn at all.

If the aircraft is turning more slowly than the needle, an apparent turn towards North, instead of away from it, will be indicated.

If the aircraft turns faster than the needle, an apparent turn less than the true turn will be indicated.

When turning towards the West from the North, the centre of gravity will be deflected to the East, and identical effects will be observed.

On Southerly headings, a change of Course to the East or West, will result in a rotation of the compass needle in the *opposite* direction. Exaggerated indications of turn will therefore be given.

(ii) If the aircraft's speed be increased when flying on an Easterly Course, the acceleration will be applied to the pivot of the magnet system. The centre of gravity of the system will, by virtue of its inertia, lag behind the pivot until constant speed is again resumed. This will result in a displacement of the centre of gravity to the West of the pivot; and a clockwise rotation of the needle.

Thus, although the aircraft may have maintained a straight Course, the compass will, while the speed is increasing, indicate an apparent turn towards the North.

Reduction of speed will similarly produce an apparent turn towards the South.

On Westerly headings changes of speed will also produce an apparent turn towards North for increase in speed and towards South for decrease in speed, although the rotation of the needle will be in the opposite direction to that for Easterly readings.

Other Causes of Deviation or Change of Deviation

65 (i). *Changes of Magnetic Latitude*

As Magnetic Latitude changes, the values of H and Z also change. (See Figure 38.)

Change of H is important only in the sense that the directive strength of a compass needle changes with it. The greater H is, the greater will be the directive strength of the compass needle and the less, therefore, will be the Deviation caused by local magnetic disturbance.

This stresses the additional importance of accurate swinging in the case of aircraft required to travel long distances, involving much change of Magnetic Latitude. Any residual "hard" iron Deviation, due to inaccurate correction of B or C, will become greater in its effect with any decrease of H, and less with any increase of H. This change in Deviation can be sufficient to cause appreciable errors in the Courses steered.

With change of Z, the strength of vertical "soft" iron magnetism will alter and the Deviation due to it will vary accordingly. The effect will be aggravated by the fact that any increase in Z is always accompanied by a corresponding decrease in H. Consequently a stronger vertical "soft" iron component will be acting on a compass needle of reduced directive strength. Thus an aircraft compass, though accurately swung to begin with, may show quite appreciable Deviation if it undergoes much change of Magnetic Latitude. The regulation contained in K.R. and A.C.I., para. 762 should be complied with in this respect.

(ii) *Electrical Effects*

It has been explained elsewhere that electric currents, whether passing in a single wire or a coil, can produce a magnetic field. In aircraft, provided that the regulation "safe distances" for electrical components have been complied with, no appreciable Deviation due to such causes should be experienced.

It sometimes happens, however, that stray wires carrying direct current find their way into the vicinity of the compass, or that electrical apparatus, such as engine revolution-counters, become magnetically energised in an unspecified manner. Such possible sources of Deviation should be tested as to their effect upon the compass during swinging.

In the case of engine revolution-counters, the only reliable test occurs where the aircraft is swung during cruising flight. Any Deviation caused thereby will be automatically dealt with during the swing.

CONSTRUCTION AND MAINTENANCE OF COMPASSES

66. Detailed construction of the different types of compass used in the Royal Air Force is given in A.P.1743. It is intended here to deal with the subject only in a general way, in order to assist those responsible for the care and maintenance of the instruments.

MAGNETIC COMPASSES

67. The most common types of magnetic compass in use are the P.6 and P.4. The construction of both is very similar, the main difference between them being in their relative sizes. The smaller P.6 compass is used here for illustrative purposes.

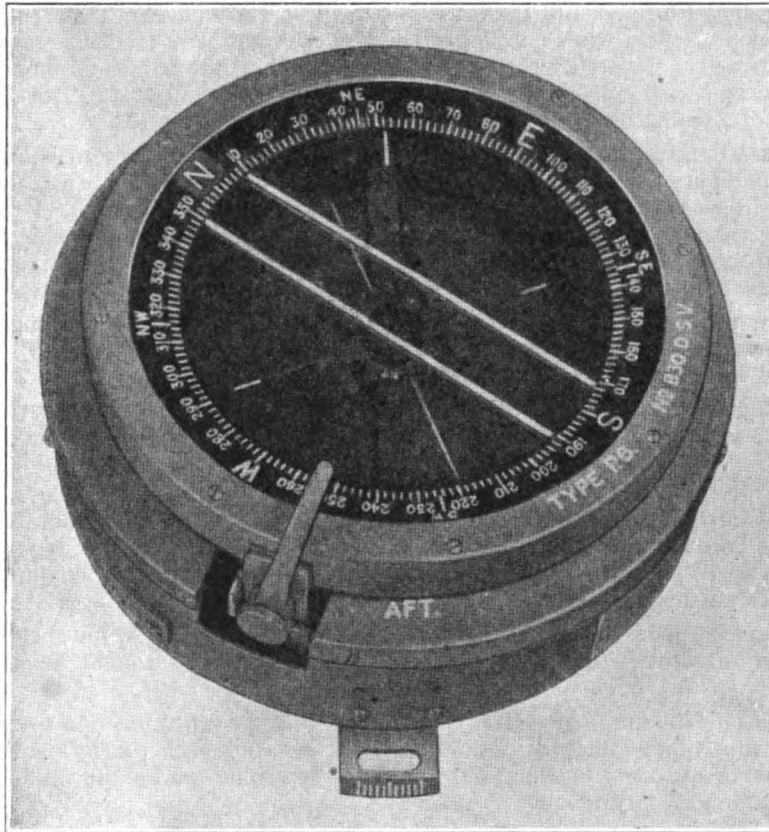


FIGURE 24. P.6 Compass.

68. The principal component of any compass is the magnet system. This consists of a number of small permanent magnets (2 in the case of the P.6) fixed parallel to each other and freely pivoted at a point above their common centre of gravity (A in Figure 26).

69. Magnet system and pivot are contained in a bowl filled with liquid. The liquid is a mixture of alcohol and water. Its main purpose is to damp the movement of the magnet system and render it dead-beat* (or aperiodic) in action. It also lessens the effective weight of the magnet system by displacement and thereby saves wear at the pivot.

* If after deflection a compass needle returns to rest without appreciable over-swinging, it is said to be "dead-beat" in action.

70. Attached to the magnet system are a number of projecting "damping" wires (Figure 26) the purpose of which is to assist in damping the movement of the system by offering resistance to the liquid. The damping wires are used to define the cardinal and quadrantal points. The N, S, E and W wires carry minute glass tubes containing a luminous compound to make them visible by both night and day. The N-wire carries a distinguishing cross-piece (G in Figure 26).

71. The liquid is kept in the bowl by a glass top. This is maintained in position and hermetically sealed by means of a brass verge ring (B in Figure 26) and rubber washer. Expansion and contraction of the liquid is allowed for by an expansion device fitted in the underside of the bowl.

72. Resting on the verge ring, and free to rotate round it, is the grid ring (Figure 25). This is graduated in the same manner as a compass card, luminised as necessary, and can be correctly oriented relative to the magnet system by means of parallel luminous grid wires (H in Figure 25). Its purpose is two-fold. First, it avoids the necessity of attaching a compass card to the magnet system itself, thereby improving the performance of the latter; second, it makes accurate steering easier, the Pilot merely having to keep the grid wires parallel to the N-S damping wire to maintain a required Course. The Course to be steered is pre-set by rotating the grid ring until the required number appears against the lubber line attached to the inside of the bowl (C in Figure 26). The grid ring may be secured in position by means of a clamping device (D in Figure 26).

73. The bowl assembly is placed in a container (Figure 27) and rests on four equally-spaced, helical bronze springs (I in Figure 27). In older compasses, rubber pads were used instead of springs. The springs take the entire weight of the bowl and thereby insulate it from vibration. By means of a device known as a floating ring (J in Figure 27), the bowl is prevented from turning inside the container, but is permitted limited movement in all other directions. Lateral movement is damped by the frictional action of leaf springs, one of which is shown at E in Figure 26.

74. The bowl is prevented from leaving the container by means of the lid ring (K in Figure 27). The lid ring overlaps cork-surfaced projections attached to the bowl (F in Figure 26). For convenience of assembly, the lid ring is in two halves.

75. Three drilled lugs are fitted to the bottom of the container for securing the compass to the aircraft. One of these (L in Figure 27) is graduated in degrees to give adjustment for coefficient A.

Installation of Magnetic Compasses

76. Compasses must never be fitted in aircraft in positions other than those officially specified. Such positions have been carefully selected so as to satisfy magnetic and other requirements. Service Units in general, however, will never have to carry out an original installation but will merely have to replace compasses already installed.

77. A new compass should be positioned so that the adjustment scale for coefficient A has equal movement in either direction. Brass or other non-magnetic screws should be used to secure the compass.

78. As a precaution, the micro-adjuster should be set to the neutral position before a new compass is adjusted for the first time. This may be achieved by rotating each pair of control heads through their maximum movement, counting the number of key turns required for this, and then turning back through half that number of turns.

Installation of Micro Adjusters

79. Micro-adjusters are usually secured to aircraft independently of the compass. They should be fitted in the approved position with securing lugs nearest to the compass and with their centres vertically below the centre of the compass.

80. If the effect of a micro-adjuster is found to be too powerful for accurate adjustment, non-magnetic washers or distance-pieces may be used to increase its distance from the compass.

81. Compasses and micro-adjusters are always marked so as to indicate which point around their circumference is *Aft*, and which *Forward*. They should always be installed with regard to such marks.

Care and Maintenance of Magnetic Compasses

82. If broken or damaged parts need replacement, or the compass fails to satisfy the requirements given in paragraph 83, the compass should be classed unserviceable and returned to the Admiralty Compass Observatory through the usual channels. A defect report should be included.

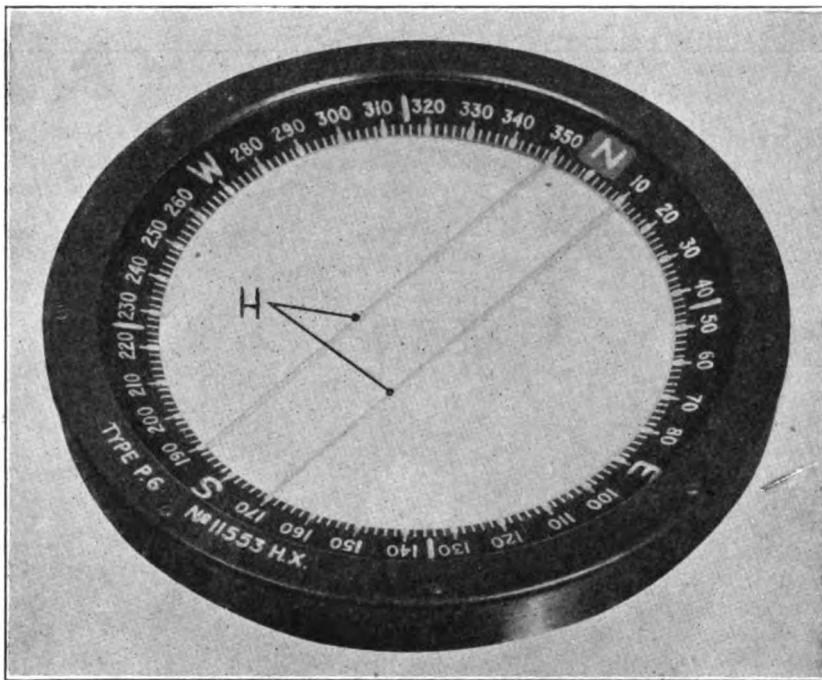


FIGURE 25. P.6 Grid Ring.

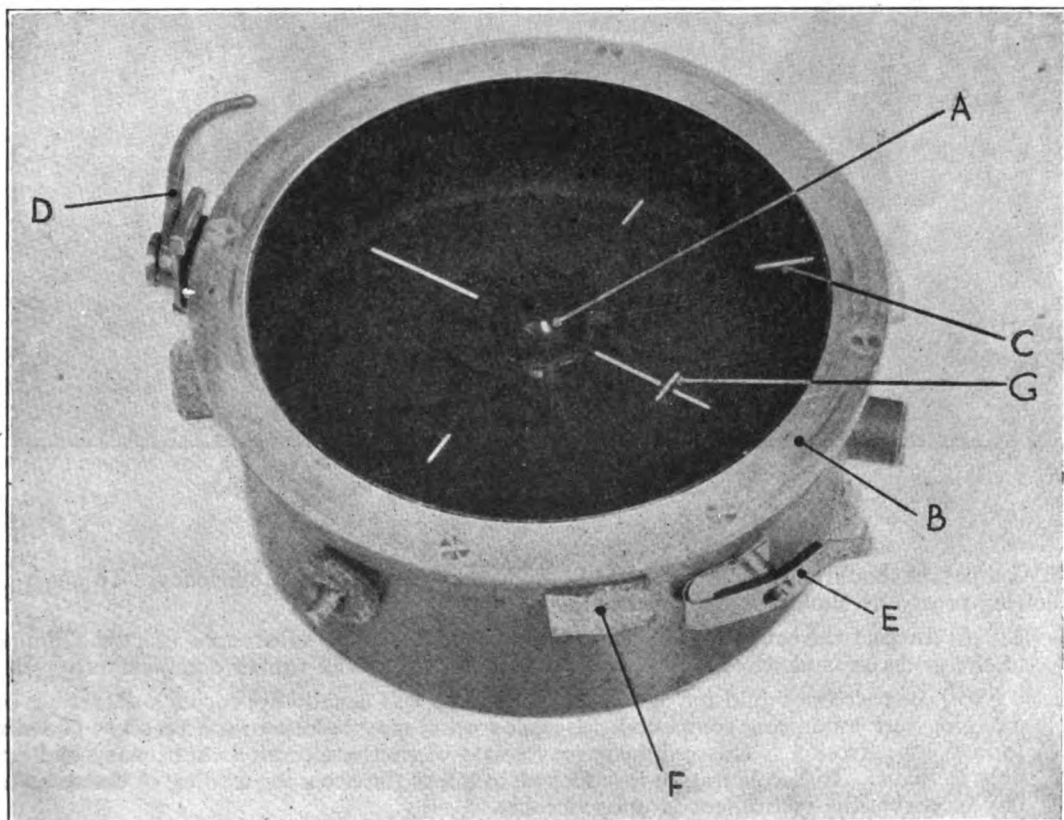


FIGURE 26. P.6 Bowl.

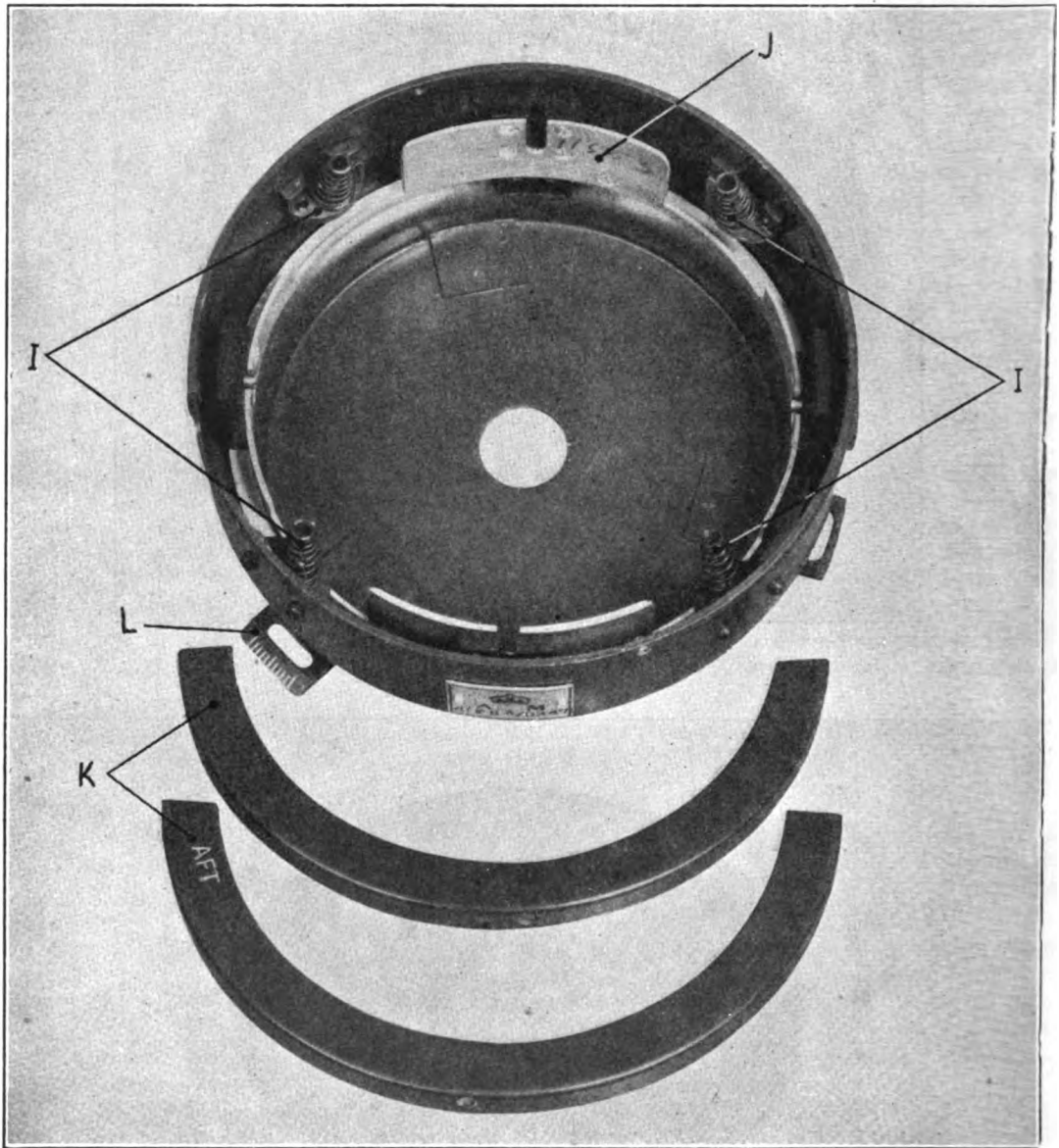


FIGURE 27. P.6 Container and Lid Ring.

83. Compasses should always be kept at the highest possible state of efficiency. To ensure this, the following procedure should be complied with before each swing :—

(i) Inspect the compass for traces of oil or petrol. These substances affect the luminosity of the grid ring and wires, obliterate graduations and attack rubber components.

(ii) Inspect the liquid for discolouration. This will usually appear as a darkening of the damping-wire luminising compound. Discolouration may be due to the presence of sediment formed by corrosion. This sediment may settle when the aircraft is stationary and appear only in flight. If discolouration is sufficient to affect the accurate reading of the compass by day or night, the instrument is unserviceable.

(iii) Inspect the liquid for bubbles. If any are present, the instrument is unserviceable. Bubbles may only appear at heights where the outside atmospheric pressure is low. If their presence under these conditions is observed, the instrument is unserviceable.

(iv) Move the compass bowl gently in all directions (except in azimuth) and ensure that no metallic contact occurs between it and the aircraft or container. Ensure that the spring or rubber vibration insulators are functioning correctly. If not, the instrument is unserviceable.

(v) Test the grid ring for freedom of rotation. If the movement is too slack, and accurate setting difficult for this reason, the instrument is unserviceable. If the movement is too stiff, the instrument is unserviceable.

(vi) Test the clamping device for efficiency, it should be slightly past the vertical position when the grid ring is properly clamped.

AT ALL TIMES KEEP COMPASSES AS CLEAN AND DRY AS POSSIBLE

Pivot Friction

84. If the action of the magnet system of a compass becomes sluggish or erratic, it should be tested for excessive pivot friction. To do this, remove the compass from the aircraft and level it. The magnet system should then be deflected through ten degrees by placing a piece of magnetic material near it, and should be held in this position for half a minute to allow the liquid to come to rest. It should then be released and the reading at which it settles carefully noted, no tapping or vibration being applied while it settles. The deflection is then repeated in the other direction and the settling position again noted. The difference between the two settling positions should not exceed 2° , but a compass may be considered serviceable if light tapping of the compass bowl will bring the difference of readings within this limit.

THE ASTRO-COMPASS

85. The Astro-compass (*see* Figures 28 and 29) consists of a Bearing Plate (1) with a movable Sighting Device (2) attached to it. The Sighting Device is set relative to the Bearing Plate so that the angle between its line of sight and a north-mark on the Plate is equal to the Azimuth of an observed Heavenly Body.

Now the Azimuth of a Heavenly Body depends on three factors, viz. :—

- (i) The Local Hour Angle of the Body (3) ;
- (ii) Its Declination (4) ;
- (iii) The Latitude of the observer (5).

The instrument is so constructed that when these values are set on the Astro-compass (the scale for each being clearly marked), and the Sighting Device is aligned on the Body, the Bearing Plate will be properly oriented and the north-mark upon it will indicate True North.

Construction

86. The Astro-compass fits into an O·5 or O·5A compass standard and may be levelled by means of Cross-levels (6) and Adjusting Screws (7).

Its base consists of a Bearing Plate (1), free to rotate against a Lubber Line (8). Two graduated Hour Angle Scales are mounted above, one in white (3a) for North Latitudes and one in red (3b) for South Latitudes. These scales are locked together and are rotated by a spring-loaded Knob (9).

Attached to the top of the Hour Angle Scales is a Sighting Device (2), which has a shadow bar and screen for use with the Sun or Moon and a prismatic star-sight for use on other occasions. Although aligned permanently with the 0° — 180° line of the Hour Angle Scales, the sights can be tilted for any

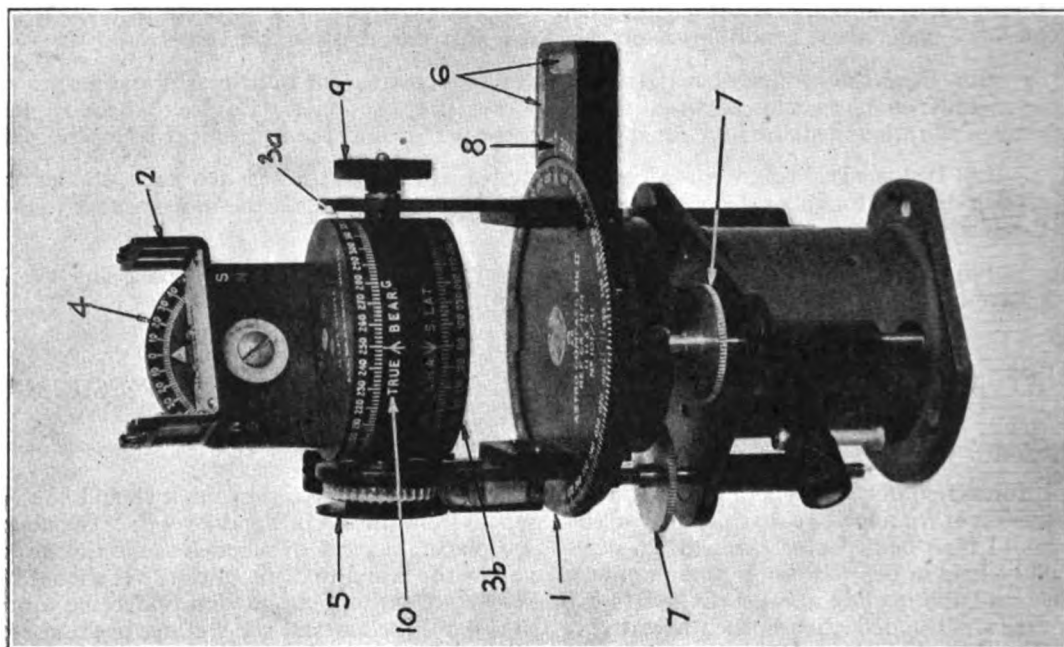


FIGURE 29. The Astro-Compass, Mk. II.

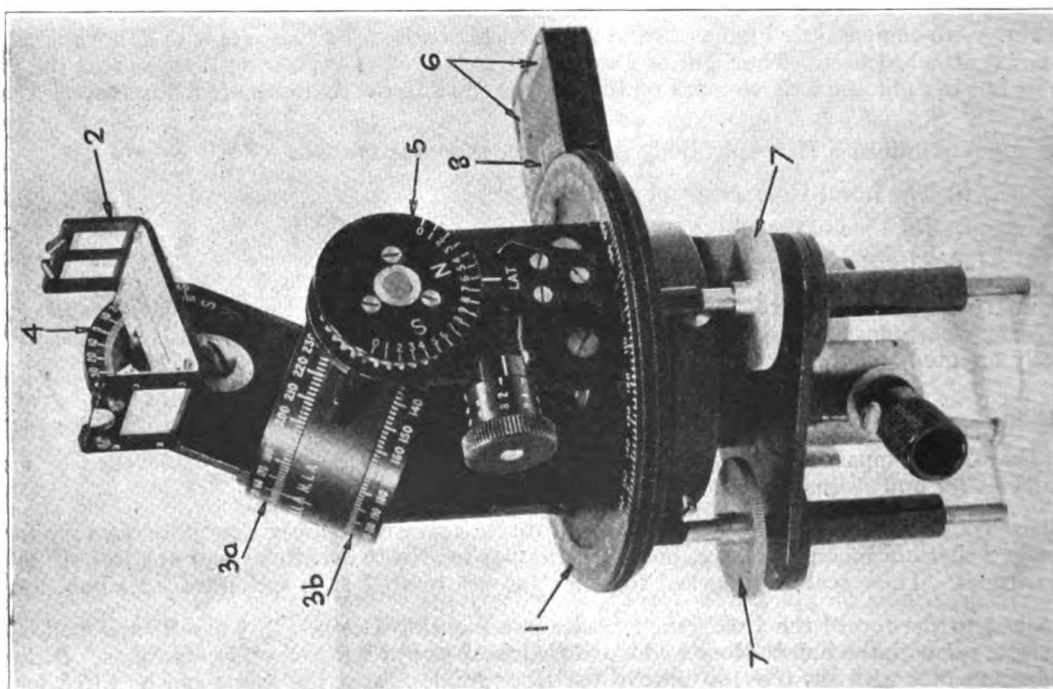


FIGURE 28. The Astro-Compass, Mk. II.

Declination between 64° N or S. The Declination is read against an arc (4), engraved in white (for North latitudes) or red (for South latitudes).

The Latitude Scale (5), white for North and red for South, is adjusted by a knob that indicates single degrees to be added to the tens of degrees marked on the Scale itself.

87. When using the Sun or a bright Moon, the Bearing Plate is rotated until the shadow from the shadow bar falls between the parallel lines on the shadow screen.

If the Heavenly Body in use cannot be sighted exactly at the imaginary intersection of the two white lines of the foresight, ensure that the sights are set so that the Body is *vertically* above or below the point of intersection. (See Figure 30.)

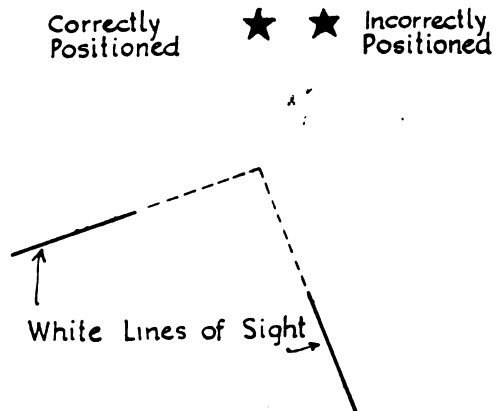


FIGURE 30. Alignment of Sights.

Operation

88. The Astro-Compass helps the Air Navigator in three important ways:—

- (i) It provides a rapid Check on the True Course.
- (ii) It enables a required Course to be steered independently of the magnetic compass.
- (iii) It can be used for taking accurate visual bearings.

When using Heavenly Bodies, those having low altitudes give the most accurate results, particularly in low latitudes.

Checking the Course

89. Method (i)

- (a) Place the instrument in its standard and LEVEL each bubble in turn with the appropriate screw.
- (b) Set the Latitude (nearest degree).
- (c) Calculate L.H.A. Body (see Chapter VII, paragraph 12).
- (d) Set L.H.A. on the appropriate Hour Angle Scale.
- (e) Set the Declination.
- (f) Rotate the Bearing Plate until the Sights are aligned on the Body.
- (g) Read the True Course of the aircraft against the Lubber Line.

Method (ii)

If an Astrograph (see Chapter VII, paragraph 40) is available, and it is desired to check the Course at night, the following method is recommended, as no reference to the *Air Almanac* is required:—

- (a) Switch on and adjust the Astrograph.
- (b) At the approximate position of the aircraft, see which star has the lower Altitude, and note the latter to the nearest degree.
- (c) Obtain this star's Azimuth to the nearest degree. This may be quickly measured as follows:—

Place the chart-table plotter, with its long edge tangential to the star's curve. Then read off the bearing on the nearest compass rose against the short edge of the plotter, in the direction of increasing altitude. Alternatively a Douglas protractor can be used.

- (d) Place the Astro-compass in its standard and LEVEL.
- (e) Set 90° on the Latitude scale.
- (f) Set the Azimuth, found at (ii) (c) above, on the Hour Angle Scale against the True Bearing Lubber Line.
- (g) Set the Altitude, noted at (ii) (b) above, on the Declination Scale.
- (h) Rotate the Bearing Plate until the star is on the sights.
- (i) Read off the True Course against the Bearing Plate Lubber Line.

Steering a Course

90. (i) Place instrument in its standard and LEVEL.
- (ii) Set the True Course required against the Bearing Plate Lubber Line.
- (iii) Set up the instrument for Latitude, Declination and Hour Angle as described in paragraph 89 (i) above.
- (iv) Instruct the Pilot to turn the aircraft until the selected Body comes on to the sights.
- (v) Maintain the Course by the Directional Gyro.
- (vi) Check Course with the Astro-Compass at intervals of not more than 15 minutes, altering the course steered on the Directional Gyro, if necessary.

Identifying a Star

91. (i) Place the instrument in its standard and LEVEL.
- (ii) Rotate the Bearing Plate until the True Course registers against the Lubber Line.
- (iii) Set the Latitude.
- (iv) Turn the Hour Angle Scale and adjust the Declination Scale until the Star is on the sights.
- (v) Read off the L.H.A. ★ and the Declination.
- (vi) Calculate the S.H.A. ★

First calculate L.H.A. γ by applying $\begin{smallmatrix} + & E \\ - & W \end{smallmatrix}$ Longitude (nearest $\frac{1}{2}^\circ$) to G.H.A. γ . (*Air Almanac*).

Then subtract L.H.A. γ from L.H.A. ★ Apply $\pm 360^\circ$ when necessary.

(vii) Enter the Inside Front Cover of the *Air Almanac* (see extracts in Chapter VII) with S.H.A. ★ and its Declination, and extract the Star by inspection. For example, the S.H.A. ★ and Declination of a Star are found to be 186° , and 15° N respectively. It will be seen that only one star, DENEbola, No. 30, has values of both S.H.A. and Declination that closely resemble these.

Obtaining a True Bearing of a Ground Object

92. (i) Place the compass in its standard and LEVEL.
- (ii) Set the True Course on the Bearing Plate against the Lubber Line.
- (iii) Set the Latitude Scale to 90° . The Hour Angle Scales are now parallel to the Bearing Plate.
- (iv) Turn the Hour Angle Knob until the object is on the sights.
- (v) Read the True Bearing on the Hour Angle Scale against the True Bearing Lubber Line.

Obtaining a Relative Bearing of a Ground Object

93. (i) Place the compass in its standard and LEVEL.
- (ii) Set 000° on the Bearing Plate against the True Course Lubber Line.
- (iii) Set the Latitude Scale to 90° . The Hour Angle Scales are now parallel to the Bearing Plate.
- (iv) Turn the Hour Angle Knob until the object is on the sights.
- (v) The Relative Bearing is then read off the Hour Angle Scale against the True Bearing Lubber Line.

Obtaining the Course from a Known Bearing of a Distant Object

94. (i) Place the compass in its standard and LEVEL.
- (ii) Set the Latitude Scale to 90° .
- (iii) Set the Known Bearing on the Hour Angle Scale against the True Bearing Lubber Line.
- (iv) Rotate the Bearing Plate until the object is on the sights.
- (v) Read the Course against the Bearing Plate Lubber Line. This Course will be True, Magnetic or Compass according to whether the Known Bearing is True, Magnetic or Compass.

Aligning the Astro-Compass Standard

95. It is imperative that all the compass standards on an aircraft are properly aligned for the Astro-Compass to function correctly. Either of the two following methods can be used on the ground.

Method (i)

- (a) Find the True Heading of the aircraft as described in paragraph 89.
- (b) Find the actual True Heading of the aircraft, by landing compass, or other external means.
- (c) Compare the two headings. If there is a discrepancy, rotate the standard until the heading by Astro-Compass agrees with the actual heading.

Method (ii)

- (a) Find the True bearing of the Astro-Compass *from* a distant landing compass.
- (b) Obtain a visual True bearing of the landing compass as described in paragraph 92.
- (c) Compare the second bearing with the *reverse* of the first. If there is a discrepancy, rotate the standard until both bearings agree.

Method (iii)

If the compass standard is on the centre line of the aircraft, the following is the quickest method :

- (a) Set a Course of 180° on the Bearing Plate.
- (b) Set the Latitude Scale to 90°.
- (c) Set 0° on the Hour Angle Scale against the True Bearing Lubber Line.
- (d) If the sights are not now aligned with the Aircraft fin or with the centre of the tail-plane, turn the standard until they are ; then secure.

Accuracy in use

96. (a) When using the Astro-Compass, it is possible to introduce appreciable errors in the courses and bearings obtained, through small errors in settings and adjustments. The instrument itself is accurate to within 2°, which means that if the settings and adjustments are correctly made, the result obtained will never be more than 2° out. More often than not the results will be within 1° or less, as the individual errors tend to cancel out rather than to accumulate.

(b) To ensure the most accurate results, the following precautions should be taken when using the instrument : -

- (i) Allot each Astro-Compass to one particular aircraft.
- (ii) When fitting the compass in its standard, avoid a possible $\frac{1}{2}^\circ$ error, due to play in the locating slot, by always rotating the compass in one direction before tightening the clamp, so that the locating key always comes up against the same side of the slot.
- (iii) Align carefully each standard fitted in the aircraft by one of the methods set out in the Astro-Compass booklet.
- (iv) Between latitudes 30° N. or 30° S., use the Astro-Compass as a bearing plate. (The true azimuth of a body may be obtained from tables as well as from the astrograph.)
- (v) At latitudes greater than 30° N. or 30° S., use a body whose altitude is less than the observer's latitude.
- (vi) Always use the automatic pilot when fitted, when making observations, and ensure that the aircraft has settled down.
- (vii) When course checking or taking bearings, take simultaneous readings of the Astro-Compass and magnetic compass.
- (viii) Always take at least five separate readings on each heading at even intervals of time. Ten readings at 30-second intervals is recommended.
- (ix) Reset the levels carefully between each reading.

THE DISTANT READING GYRO-MAGNETIC COMPASS

97. The ordinary types of magnetic compass, as fitted in modern aircraft, suffer from two disadvantages. First, they are affected by acceleration and deceleration which render them useless in turns and directionally unstable under conditions of varying Course and airspeed. Second, the armour-plating in and around the Pilot's cockpit screens the Earth's field and makes any compass situated therein sluggish and inaccurate. The Distant Reading Gyro-magnetic compass is designed to overcome both these difficulties. Reference should be made to AP. 1275 B for detailed technical information relative to the D.R.C.

Construction

98. The main component of the instrument, known as the *Master Unit* (See Figure 31), is situated normally in the tail of the aircraft, well away from any armour-plating or other sources of local magnetic disturbance. It consists first of a small, accurately constructed gyroscope, with a horizontal spin axis, which is rotated electrically at about 12,000 r.p.m. It is, therefore, very stable in space and the aircraft can turn and manœuvre without affecting the direction of the axis of the gyroscope. The gyroscope can thus be used as a fixed datum from which to measure changes of Course.

Any change of Course results in a corresponding change of angle between the gyroscope's axis and the fore-and-aft line of the aircraft. This movement sets an electric motor revolving in an appropriate direction to drive an electric transmitter system. The function of the transmitter system is to *measure the change of angle between the fore-and-aft line and the gyroscope's axis, and to indicate it on a number of Repeater dials, suitably placed throughout the aircraft.* (See Figures 32, 33.)

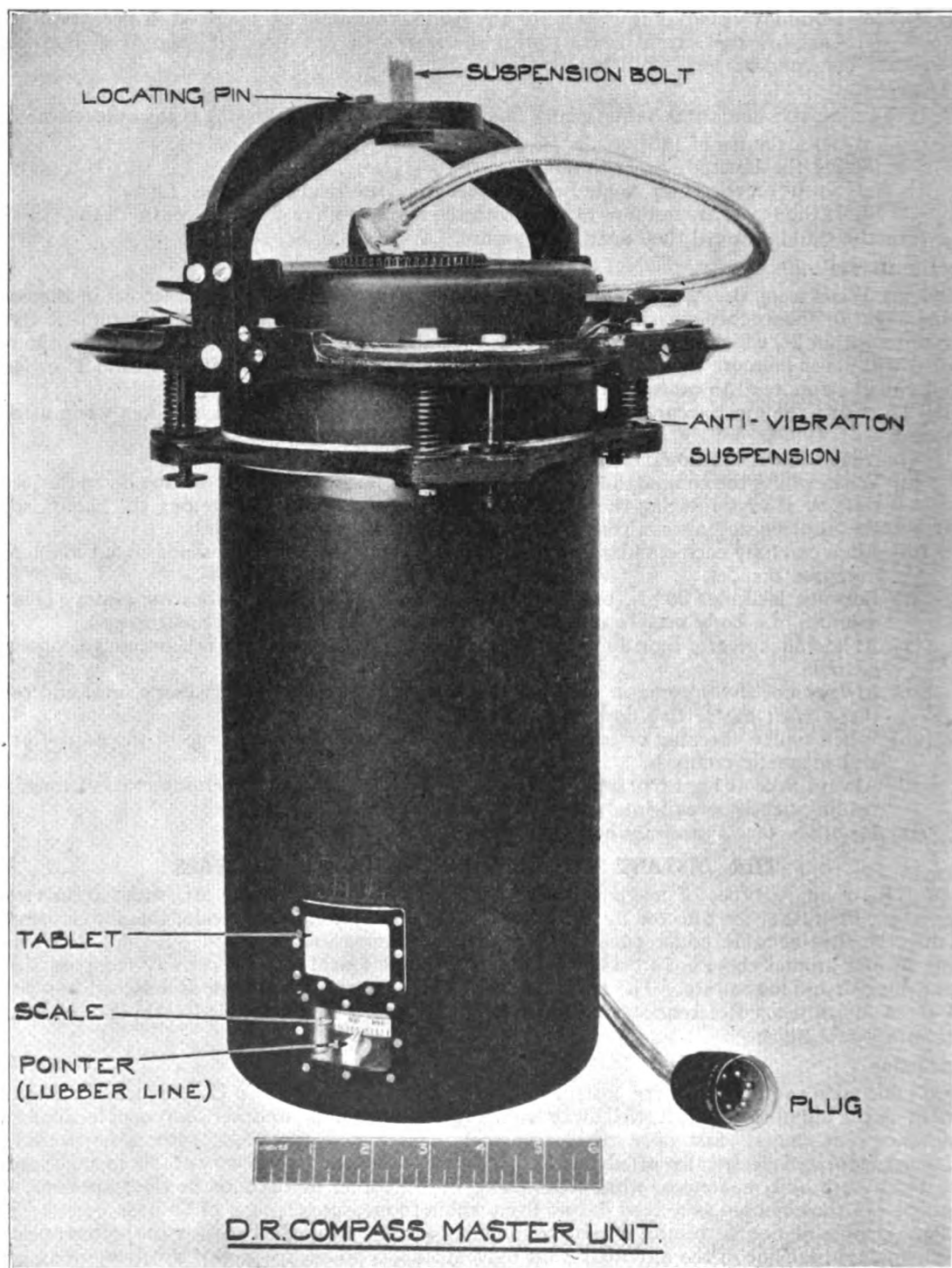


FIGURE 31. The Master Unit of the D.R. Compass.

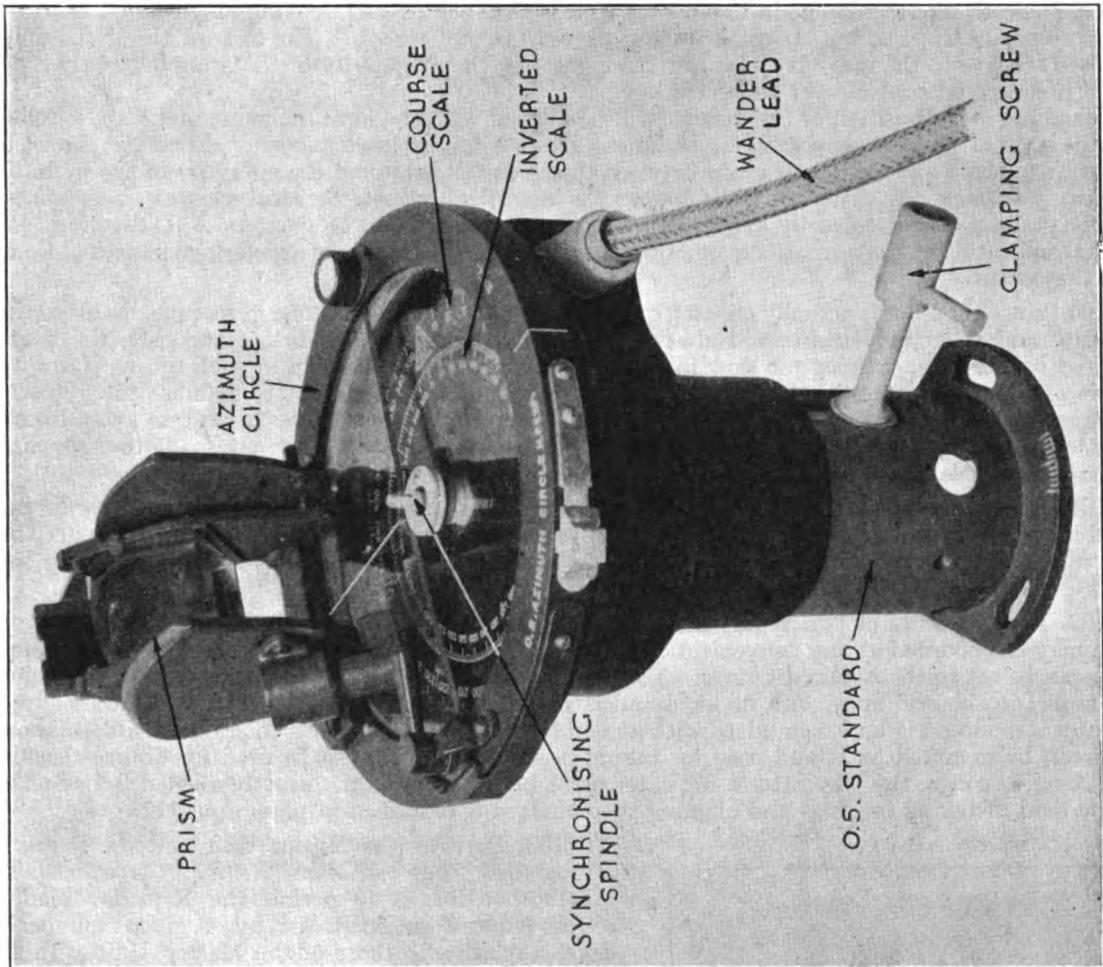


FIGURE 33. The Navigator's Repeater.

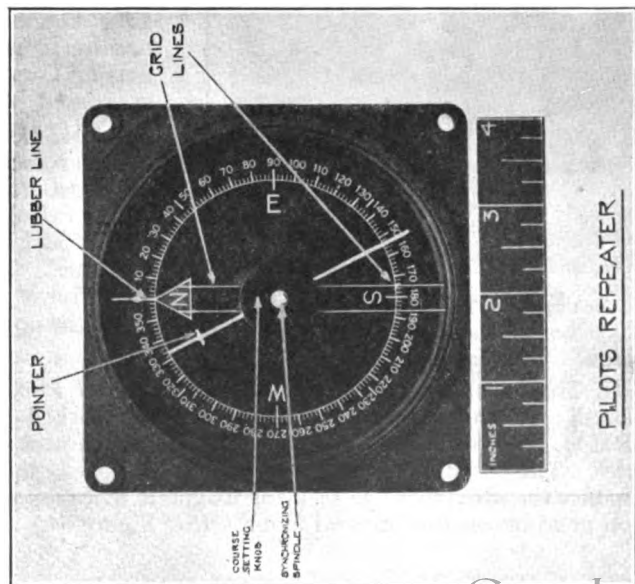


FIGURE 32. The Pilot's Repeater.

99. Beneath the gyroscope in the Master Unit is situated a North-seeking magnet similar to that of an ordinary compass, but pivoted on top as well as underneath. The axis of the gyroscope is stabilised relative to the mean position of this magnet, by the magnet itself exercising indirectly a slow rate of precessional control over the gyroscope.

Since the mean position of the magnet will be aligned with the local magnetic meridian, it follows that the axis of the gyroscope will be stabilised relative to the local magnetic meridian. Since the Repeaters indicate any change of angle between the aircraft's head and the spin axis of the gyro, *they will thereby indicate any change of angle between the aircraft's head and the local magnetic meridian.* If suitably graduated and correctly synchronised in the first place, the Repeaters will, therefore, give constant indication of the aircraft's magnetic Course, as well as accurately registering changes of Course when they occur.

100. Since the Pilot is actually steering on the transmitted indications of a gyroscope, his alterations of Course and other movements will always be indicated correctly and instantaneously, the control exercised by the magnet being too slow to register its own erratic behaviour at such times. Over long periods of time, however, the control exercised by the magnet is sufficient to stabilise the gyroscope relative to the magnetic meridian and check any tendency of the gyroscope to precess away from it. Thus, by combining magnet and gyroscope, the desirable qualities of the one are made to compensate for the undesirable qualities of the other.

101. The Repeaters themselves are not affected by local magnetic interference and may be positioned in the aircraft where most convenient. Up to six Repeaters can be operated by the Master Unit. Since all the Repeaters are actuated by the same transmitter, other members of the crew can have accurate indications of the Course being steered by the Pilot at any instant.

102. Repeaters are of two types, one for Pilots and the other for Navigators. The Pilot's type, which may be mounted at any convenient angle, has grid lines fixed on its face and a movable Pointer which can be set to the required Course. To steer this Course, the aircraft is turned until the Pointer lies parallel to the grid lines, with its head under the head of the grid lines. The Navigator's type of Repeater is mounted in an 0.5 standard with its dial horizontal. It is so designed that a No. 4 Azimuth Circle can be mounted on it and used for taking bearings. It can also be used for Course-checking. For taking bearings, the Navigator's Repeater must be mounted in a correctly-aligned 0.5 standard. The method of taking bearings and aligning the standard is described in paragraph 112.

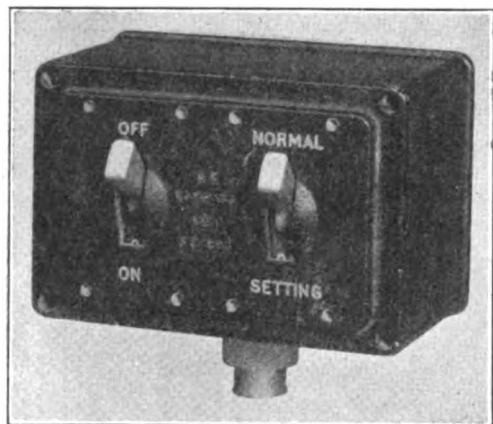


FIGURE 34. The Control Panel.

Operation

105. The instrument is provided with a *Control Panel* which is usually mounted on the Pilot's dashboard. It contains two switches, the first marked "ON"—"OFF" and the second marked "NORMAL"—"SETTING". The first switch operates the power and is connected to the aircraft batteries. The second, when at "SETTING", speeds up the magnet's control over the gyroscope, and enables the instrument to seek the magnetic meridian quickly when necessary. The "NORMAL" position must be used for general flying. (See Figure 34.)

103. Between the Master Unit and the Repeaters is installed the *Variation Setting Corrector*. The function of this is to permit the Repeater readings to be reduced or increased by a given number of degrees relative to those of the Master Unit. In this manner local Variation up to 30° E or W may at present be allowed for and Repeaters then indicate True Courses instead of Magnetic. To do this it is necessary merely to turn the knob of the Variation Setting Corrector until the local Variation is set on the graduated scale. (See Figure 35.)

104. If, every time the Navigator has reason to consider local Variation, he sets it on the Variation Setting Corrector, he can ignore Variation altogether in his calculations. His work will thereby be much simplified, as the Courses he gives to the Pilot need only be True. As explained later, the Variation Setting Corrector is also used when synchronising the Repeaters. It can be operated *only when the power is on.*

(i) *Before flight.* To start up, switch to "ON" and "SETTING". The Repeaters will then be seen to surge periodically until, after a few minutes, they finally settle down and oscillate over a range of 8° — 10° . When this occurs, put the second switch to "NORMAL". Check synchronisation (see paragraph 110 (iii)) and adjust if necessary. The instrument is then ready for flight.

(ii) *During flight.* The instrument should require no attention during flight. If, however, its indications appear to be erratic, or the gyroscope is "toppled" by exceeding the limiting angles of 70° of bank, climb or drive, put the second switch to "SETTING" for a few minutes before returning it to "NORMAL". Occasionally check the Repeaters against the stand-by magnetic compass to ensure that no failure of the instrument has occurred due to enemy action, interruption of the power supply or other causes.

(iii) *After flight.* Switch "OFF" only when the aircraft has finally come to rest.

Adjustment and Synchronisation

106. Since the Master Unit depends for its action upon a North-seeking magnet, the latter must be compensated for any local magnetic interference. Owing to the favourable position in which the Master Unit is placed, corrections should be small and final Deviations negligible. The swing is carried out with the instrument running as in flight, with the second switch in the "NORMAL" position.

107. A small window is provided in the Master Unit Cover through which the aircraft headings can be read against a lubber line. (The window is usually at right-angles to the fore-and-aft line of the aircraft. Both lubber line and Course scale are also set at right-angles to the fore-and-aft line to compensate for this.)

108. When reading the Master Unit scale on each heading, a certain amount of visual interpolation is required to allow for the continual rapid "hunt" or oscillation of the scale. This hunt, which is essential to the working of the instrument, is of the order of $\frac{1}{2}^{\circ}$ on either side of the correct heading. It is, therefore, necessary to watch the scale carefully for a minute or so in order to decide the mean reading indicated by the lubber line.

109. A micro-adjuster is fitted to the underside of the Master Unit. Since the instrument takes some minutes to settle down after each alteration of the micro-adjuster, the Coefficient method of swinging is recommended owing to the smaller number of adjustments required. The *First Phase* of the swing should be carried out as specified in paragraph 42.

110. When operating the micro-adjuster, care must be taken to ensure that the Master Unit scale has settled down to a constant reading after each adjustment, before proceeding with further adjustments. Carry out the *Second Phase* (a check-swing on all 8 points) and calculate coefficient A. Thereafter proceed as follows:—

(i) Assume the correction has been made for coefficient A and, if the residual Deviations are sufficiently large to warrant such a step, prepare Deviation Cards in the usual manner. One card should be placed near the Pilot's Repeater and one near the Navigator's Repeater. For future reference, enter the algebraic value of coefficient A and the date on the tablet provided above the window in the Master Unit Cover.

(ii) Go to the Variation Setting Corrector and slacken off the screws holding the lubber ring in place. Adjust the position of the lubber ring so that it can be moved an equal amount in each direction. Turn the knob until the scale reads approximately zero.

(iii) With the aircraft still on the last heading used in the swing, synchronise all the Repeaters as closely as possible with the Deviation Card reading for that heading. To do this, determine what the Repeaters should read by adding the algebraic value of coefficient A to the Master Unit reading.

Example.—Master Unit reading = 318° ; and Coefficient A = -2°
 $\therefore$ required Repeater reading = $318^{\circ} + (-2^{\circ})$
 $= 318^{\circ} - 2^{\circ}$
 $= 316^{\circ}$

Having determined this figure, fit the key used for the micro-adjuster over a similar spindle in the centre of each Repeater. When the key is pressed inwards against a spring it is possible to turn the Repeater card, though only in steps of 3° . It may not, therefore, be possible to make the Repeater read exactly the required figure. It is, however, essential that all the Repeaters read the same as each other.

(iv) Now turn the knob of the Variation Setting Corrector until the Repeaters show accurately the required reading. By this means final adjustment to within $\frac{1}{4}^\circ$ is obtained.

(v) Re-set the loosened lubber ring to make the scale read zero and secure it in this position with the holding screws.

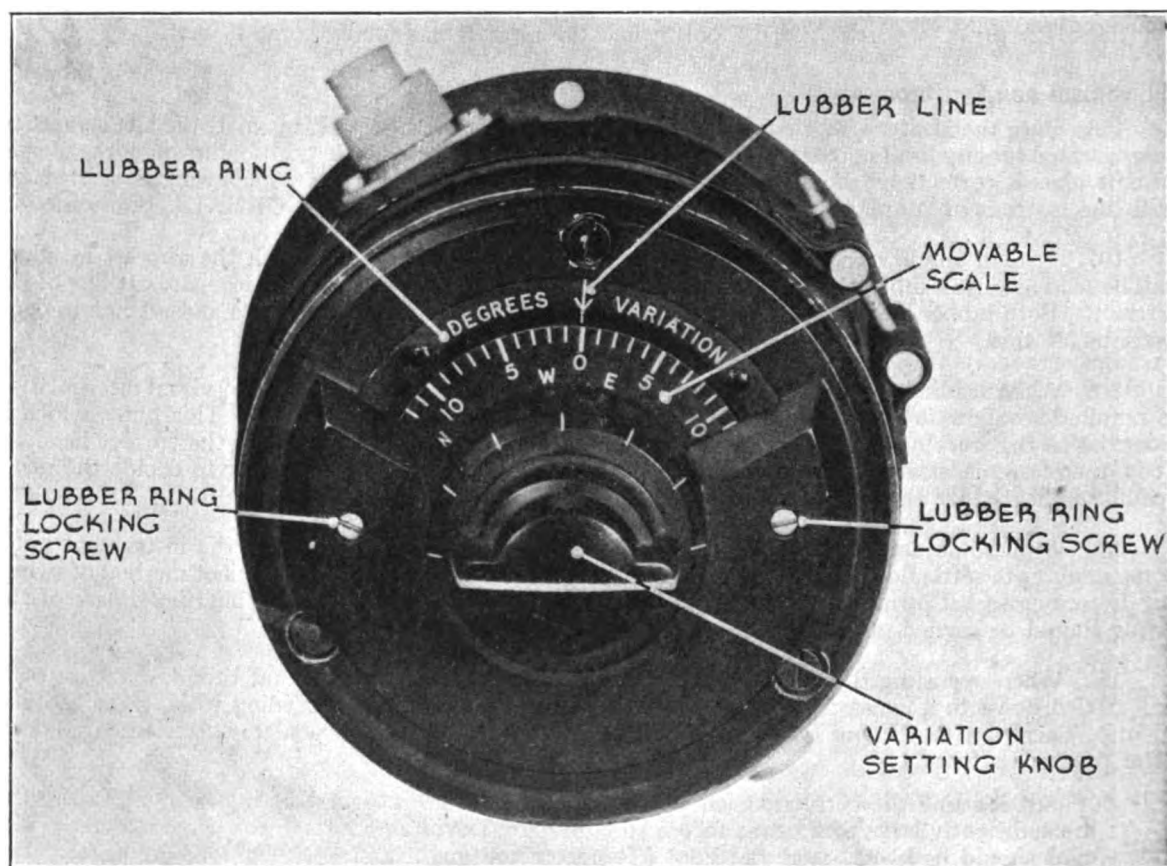


FIGURE 35. The Variation Setting Corrector.

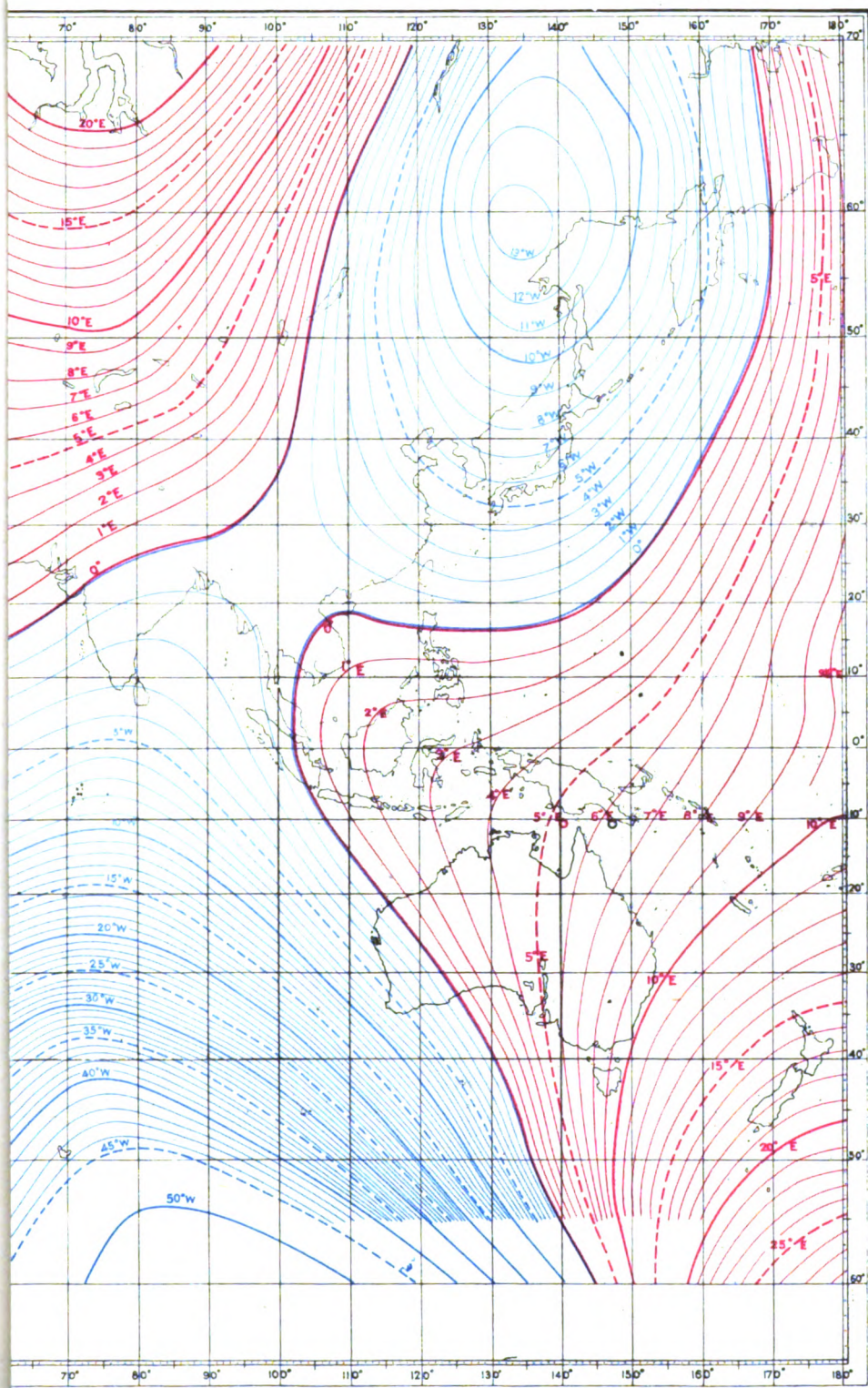
111. This completes the whole operation. The Master Unit has been corrected for magnetic interference. The coefficient A of the Master Unit has been eliminated from the Repeater readings and the latter have all been synchronised. The instrument is now ready for use.

Swinging should be carried out on installation and subsequently at intervals not exceeding 8 weeks.

Alignment of the Navigator's Repeater Standards

112. To ensure that the standards for the Navigator's Repeater are aligned correctly in the fore-and-aft line of the aircraft, the undermentioned procedure should be followed :

(i) With the instrument running as in flight and the aircraft on any convenient heading, place a landing compass, or other suitable type of bearing compass, at least 300 yards away and where it is easily visible from the Navigator's Repeater position. Both landing compass and aircraft should be well clear of any local magnetic disturbance.



RE 36- CHART OF MAGNETIC VARIATION (1937)

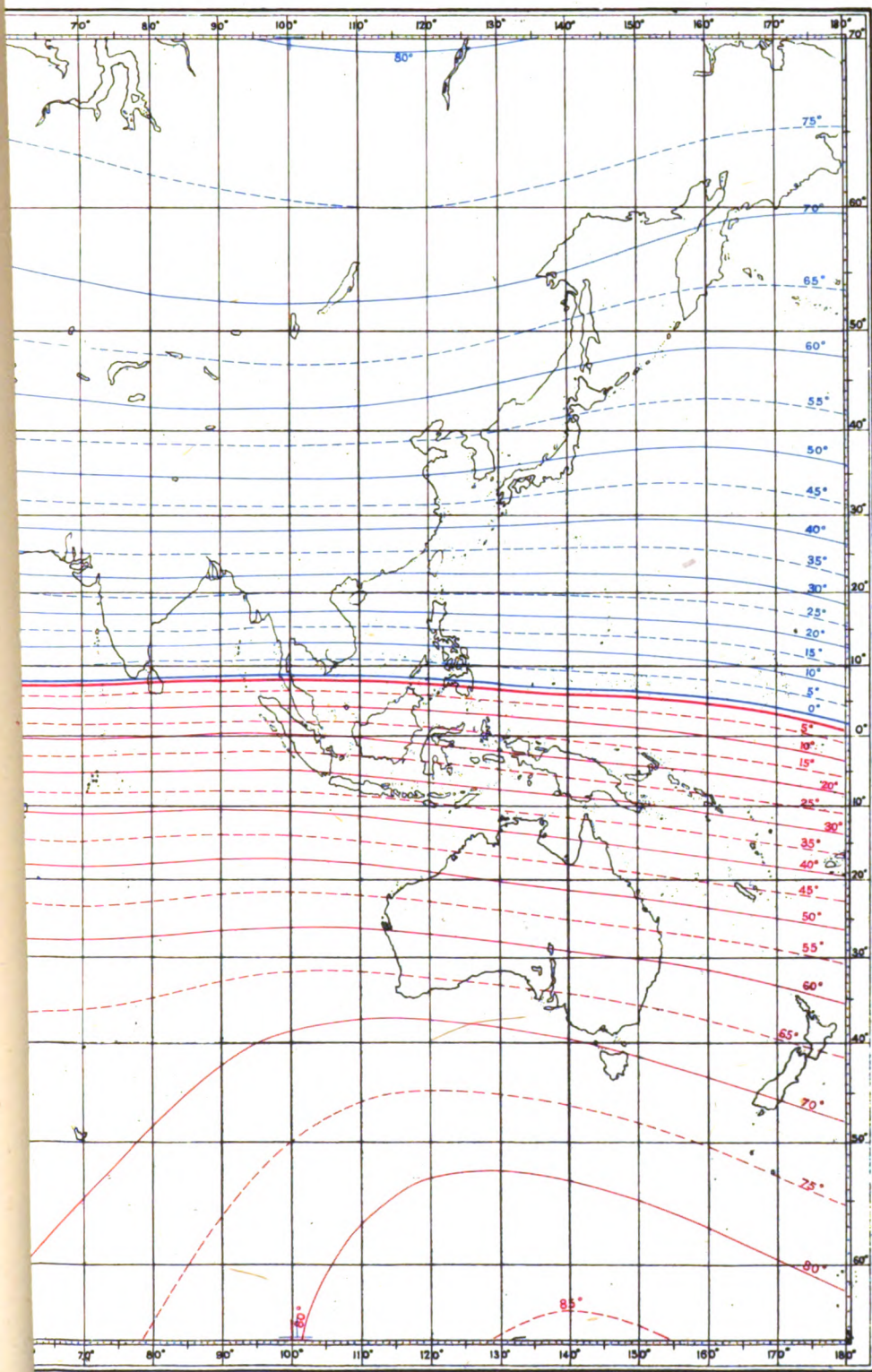


FIGURE 37. CHART OF MAGNETIC DIP (1922)





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- (ii) Take a bearing of the Navigator's Repeater position with the landing compass.
- (iii) Align the sights of the Navigator's Repeater azimuth circle on the landing compass. Adjust the prism until the reflection of the inverted scale of the Repeater card can be seen, and read off the bearing of the landing compass opposite the centre line of the prism. This is the normal procedure employed for taking bearings with this type of azimuth circle.
- (iv) Correct the bearing obtained from the Navigator's Repeater for Deviation, and compare it with the *reverse* of the bearing obtained from the landing compass. The Deviation applied to any bearing taken with the Navigator's Repeater or any other type of magnetic bearing compass, should be that appropriate to the *heading of the aircraft at the time*.

Functioning Tests

113. The following tests for correct functioning should be applied as a matter of routine after approximately every 50 operating hours of the instrument. They should also be applied if the instrument, apart from an obvious breakdown, is at any time suspected of unsatisfactory behaviour :

- (i) Place the aircraft's head approximately on East or West.
- (ii) Start and run up the instrument in the usual manner.
- (iii) Inspect the scale on the Master Unit by viewing through the window in the bottom cover ; the " hunt " of the scale should be continuous and over a range of not more than $1\frac{1}{2}^{\circ}$, nor less than $\frac{1}{2}^{\circ}$. (The second switch should be at " NORMAL ").
- (iv) Put the second switch to " SETTING " ; the Repeater cards should oscillate slowly over a range of between 3° and 8° .
- (v) Return the second switch to the " NORMAL " position and note the reading on the Master Unit scale when it has settled down to a constant heading. Now tilt the instrument by moving the bottom end of it in an Easterly direction. Hold it in this position until the scale reading has changed about 5° , then release and wait two minutes before taking the reading again. Repeat by tilting in the opposite direction, i.e., Westerly, and read again. The two readings should not differ by more than 2° .
- (vi) Note the readings on the Master Unit scale and on the Repeaters. Put the second switch to " SETTING ". Push the bottom of the Master Unit in an Easterly direction to the limit of the gimbal stops, and hold it in this position until the Master Unit scale reading has increased by at least 40° . Put the second switch at the " NORMAL " position. Let the unit return to the vertical, and note the readings on the Master Unit scale and on the Repeaters simultaneously. (An assistant is required for this.) The Master Unit scale will now be turning slowly back to the original reading. While this is in progress, keep the unit swinging to and fro about 3° and note the time taken for the reading to decrease by 20° .
- (vii) Repeat (vi), tilting the unit in a Westerly direction. The scale reading will, in this case, decrease.
- (viii) The time-intervals, noted in (vi) and (vii), should not differ by more than 3 minutes, and the maximum interval should not be more than 7 minutes.
- (ix) The changes in the Repeater readings must correspond to those in the Master Unit scale readings to within 1° at all times during (vi) and (vii).
- (x) Set the scale of the Variation Setting Corrector to read zero against the lubber's line. Note the Repeater readings and then turn the knob till the scale reads 10° West. This should *decrease* the Repeater readings by 9° — 11° . Now turn the knob till the scale reads 10° East. This should increase the Repeater readings by 9° — 11° from the original readings.
- (xi) Repeat (x) with the pointer of the Pilot's Repeater restrained by means of the knob against moving with the card. The change in Repeater readings should be as in (x).

If the above tests do not produce satisfactory results, the necessary adjustments should be carried out only by a qualified instrument-maker or instrument repairer.

THE PIONEER MAGNESYN COMPASS

Introduction

114. The Pioneer Magnesyn Compass consists of :—

- (a) The Transmitter.
- (b) The Repeater.
- (c) The Inverter.
- (d) The Harness.

This equipment enables a Magnetic Compass Unit, which is incorporated in the Transmitter, to be installed in a part of the aircraft reasonably free from magnetic disturbances, and provides electrical transmission of the direction of the aircraft, as defined by the Compass Unit, to a Repeater mounted in the pilot's cockpit. The Transmitter Unit itself provides no visible indication of heading, and all readings are taken at the Repeater. The power required for the transmission is derived from an Inverter, which is a small motor generator, for which a supply of 24 volts, D.C., is required.

The Harness consists of the necessary screened connecting leads and junction box.

The Transmitter

115. This unit is essentially a liquid-filled compass, with a single-pivot, semi-buoyant magnet system, provided with damping vanes, and supported by a spring-mounted cup jewel. The magnet, which is within the float, is in the form of a disc, magnetised along a diameter. The bowl has upper and lower compartments, the upper one acting as a bubble trap, and sealed by a diaphragm to relieve temperature effects in the liquid, and the lower one containing the magnet system.

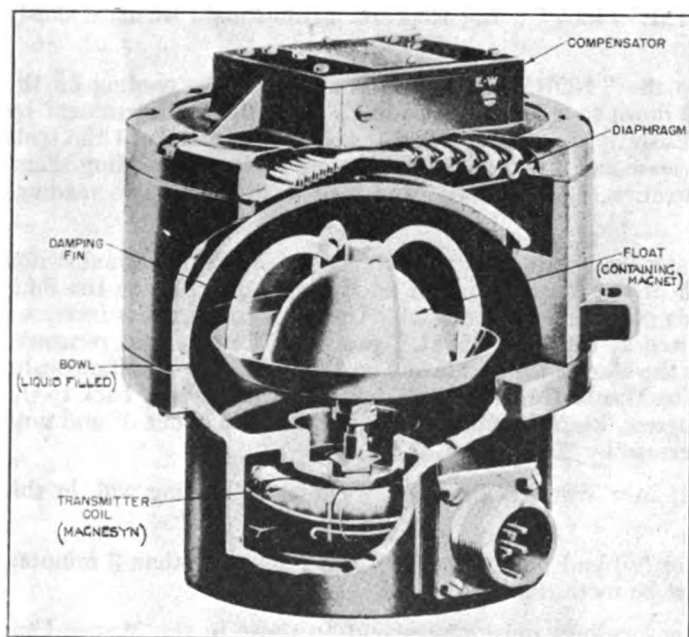


FIGURE 39. Cutaway View of Compass Transmitter.



FIGURE 40. The Transmitter.

116. Below, and external to, this compass bowl, and having no mechanical connection with the magnet system, is the Magnesyn Transmitting Element, by which the angular position of the magnet system is transmitted to the Repeater. This Transmitting Element makes use of the fact that, if certain magnetic materials are subjected to a steady magnetic field, and at the same time magnetised by an alternating current, provided the relative values of the field and the alternating current are correctly chosen, then an additional voltage is generated in the exciting winding that is twice the frequency of the exciting voltage.

117. The Magnesyn Transmitting Element has a ring of such material placed horizontally below the compass bowl. The ring has a continuous winding on it, the start and finish of this coil being adjacent. There are also tapings at 120° and 240° from the start and finish. The magnet of the Compass Unit provides the steady magnetic field, and alternating current is supplied to the winding by the Inverter.

118. As the aircraft and, therefore, the Compass Unit, turns with respect to the Magnetic Meridian as defined by the magnet, the angular position of the steady magnetic field with respect to the fore-and-aft diameter of the transmitting coil changes, with the result that the double frequency voltage is distributed round the winding accordingly. This voltage distribution may now be used to indicate the direction of the compass magnet at some remote position.

119. An adjustable corrector box, containing two pairs of magnets identified as E-W and N-S to compensate for coefficients B and C respectively, is mounted on the top of the Transmitter Unit. It is necessary to provide a separate, shock-absorbing mounting for the Transmitter Unit, in addition to the spring-mounted cup jewel in the compass bowl.

The Repeater

120. This instrument translates the angular distribution of the double-frequency voltage developed at the transmitter into angular position of a pointer, so that the direction of the aircraft, as defined by the compass magnet, may be read at some point remote from the Transmitter Unit. The Repeater Element is a smaller version of the Magnesyn Transmitter Element, consisting of a coil on a ring of special magnetic material and a double-pivoted magnet system. As in the compass, the magnet is in the form of a disc, and magnetised along a diameter.

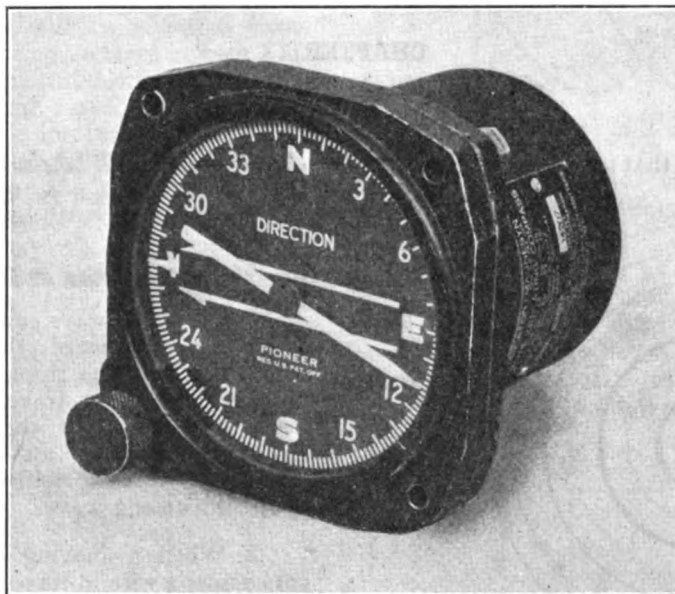


FIGURE 41. The Repeater.

To avoid magnetic interference with the repeater magnet, the whole Repeater Element is screened.

The repeater coil is excited by the same supply as the Transmitter, and the double-frequency voltage applied by two further tapings on both transmitter and repeater coils situated at 120° and 240° from the start and finish of the winding. The effect of the double-frequency voltage superimposed on the exciting voltage is to produce a unidirectional magnetic field along a diameter of the repeater ring, with an angular position corresponding to that of the compass magnet. The repeater magnet sets itself in this field, thereby reproducing an indication of the heading of the aircraft, as defined by the compass magnet.

The repeater magnet system carries a pointer which indicates heading on a suitable dial. Two "grid lines", mounted co-axially with the pointer, and rotated by a small knob on the front of the Repeater, are provided for parallel steering.

The Repeater is mounted with the dial vertical on the pilot's instrument panel.

The Inverter and Harness

121. The Inverter is a small motor generator with a D.C. armature, carrying a six-pole, permanent magnet. The stator has separate D.C. and A.C. field windings. The D.C. input is at 24 volts, obtained from the aircraft supply system, and the A.C. output is 26 volts at 400 c.p.s.

The Harness consists of the necessary screened and bonded flexible leads, junction box and plug and socket couplings for connecting the various units of the equipment.

Operation

122. Before using the Compass, the 24-volt D.C. supply must be switched on, otherwise there will be no transmission from the Compass to the Repeater.

The repeater pointer, as has been explained, reproduces the movements of the compass magnet, so that, for flying purposes, the Repeater is regarded in the same way as the usual direct-reading Compass.

Heading is read off the dial, which is luminised every 2°. The 30° and Cardinal Points are marked in addition.

For steering a given course, the grid-lines are set to the required direction by turning the small knob at the front of the Repeater, and the aircraft is flown so that the indicating pointer is maintained parallel with, and pointing in, the same direction as the grid lines.

The pointer and the grid lines are luminised.

CHAPTER IX

WIRELESS DIRECTION-FINDING

"And the moral of that is—'Take care of the sense, and the sounds will take care of themselves.'"

ALICE IN WONDERLAND.

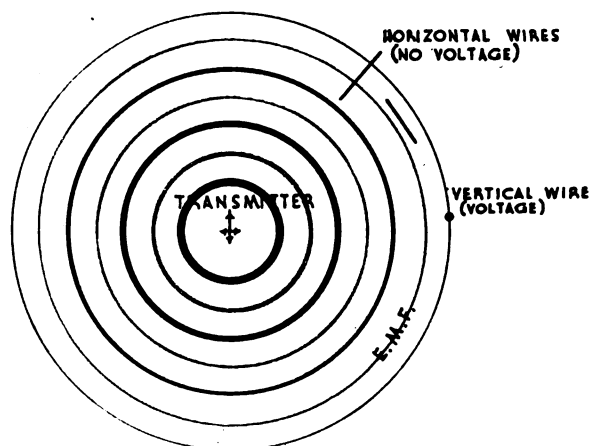


FIGURE 1. Plan View of Wave Passing Three Wires.

Directional Properties of Loop Aerials

1. The radio wave emitted by a transmitting aerial travels outwards through the surrounding space, much as the ripples caused by a stone dropped into water travel out in all directions over the surface of the water. The wave structure embodies an electro-magnetic field with lines of force at right-angles to the direction of the advancing wave.

2. When a moving electro-magnetic field cuts across a wire in its path a voltage is induced in the wire. If, however, the wire lies in the same plane as the field, no such voltage is induced. (See Figure 1).

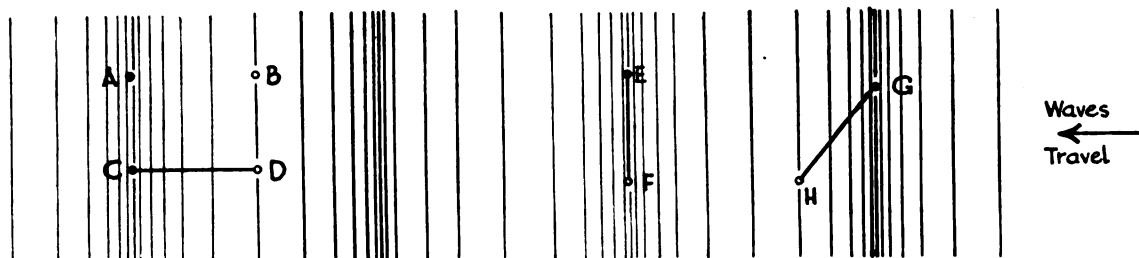


FIGURE 2. Plan View of Wave Passing Various Vertical Aerials.

3. Consider the horizontal radio wave seen in plan view in Figure 2 as it meets different aerials in its path. When the radio wave meets a vertical straight-wire receiving aerial, A, the horizontal electro-magnetic field induces a voltage in the aerial. Since the field pulsates at the frequency of the transmitter, the induced voltage in A will similarly alternate at this frequency, growing from zero voltage to a *positive* maximum, dying away to zero again, growing to a *negative* maximum and dying away again to zero during each complete cycle. This variation of voltage can be expressed as a graph, as in Figure 3.

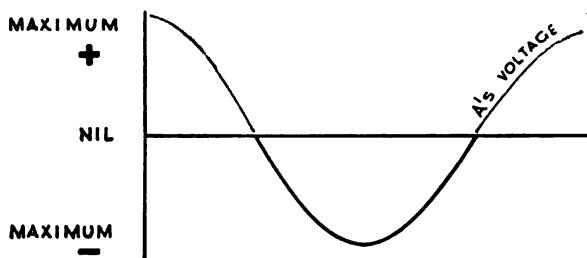


FIGURE 3. Graph of Voltage Induced in A.

4. The bulk of W/T direction-finding depends upon the reception of the wave by spaced vertical aerials. Consider A and B in Figure 2, two similar straight-wire aerials lying one behind the other in the path of the wave's advance, and separated by a small distance, compared with the distance separating them both from the transmitter. Alternating voltages will, as stated above, be induced in each of the two aerials, and since the two aerials are practically at the same distance from the transmitter, the field strength of the wave will be equal at each aerial, and the alternating voltages in each will be of equal maximum intensity. They will differ in one important respect, however, in that, since at any given instant the two aerials will cut the wave at slightly different points (e.g., one on a crest and the other slightly before or after a crest), the two voltages will be slightly "out of step." This *difference of phase*, as it is termed, between the voltages in the two aerials is illustrated in Figure 4.

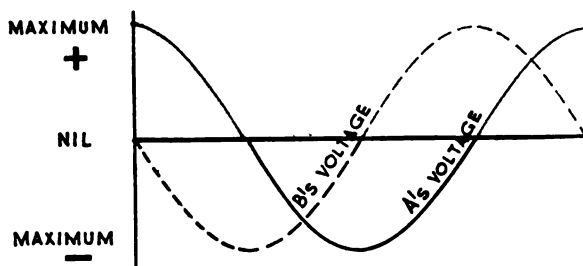


FIGURE 4. Voltages in A and B Out of Phase.

5. Now join the two aerials top and bottom by a pair of conductors, as C and D are joined in Figure 2. Since the voltages in the two vertical limbs of the loop thus produced are always out of phase, a *current* will flow round the loop in an attempt to balance the difference in voltage. Since the voltages are alternating, the current will also alternate, at the frequency of the transmitter. This is shown in Figure 5, where the alternating current in the *connected* vertical aerials C and D is illustrated diagrammatically. If this alternating current is fed into a radio receiver it may be converted into *sound waves*.

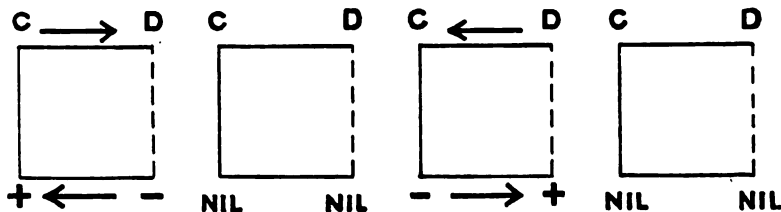


FIGURE 5. Alternating Current Induced in C and D.

6. If instead of placing the loop in line with the wave's advance it is rotated through 90° , to lie at right-angles to the line of advance of the wave, like E and F in Figure 2, both vertical members cut the wave at the same moment, i.e., a crest will reach both members at the same instant of time. In this case then, the voltages in the two vertical limbs of the loop are always exactly in step, and thus *no current will flow* round the loop at all, and consequently no sound waves will be produced by the receiver. (See Figure 6.)

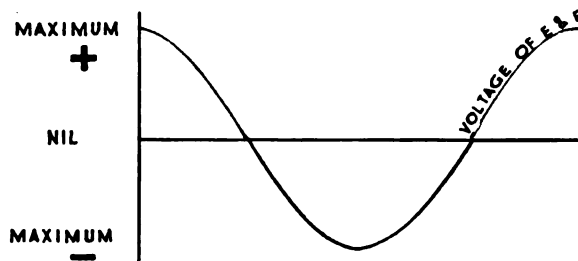


FIGURE 6. The Voltages in E and F In Phase.

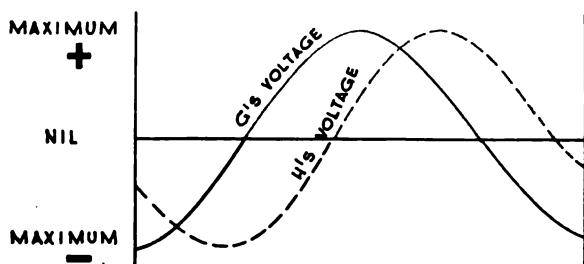


FIGURE 7. Voltages in G and H Out of Phase.

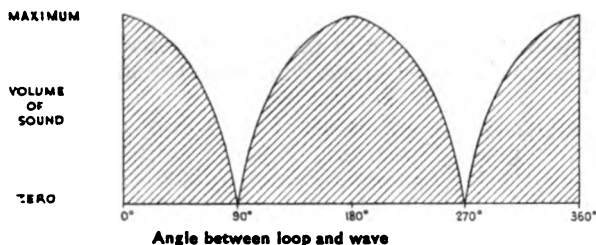


FIGURE 8. Signal Strength Related to Loop Direction.

acting solely as conductors for the current produced. Under certain conditions the electro-magnetic field may not, in fact, be horizontal, and the accurate directional properties of the loop will be seriously impaired. These conditions are examined later.

Sense Determination

10. When an aircraft loop is connected to a receiver tuned to a given station, and rotated through 360° , two positions will be found, 180° apart, which give minimum signal strength. These sharply-defined positions of the loop occur when the loop is at right-angles to the advancing wave, and serve to indicate the direction from or to which the wave is travelling. Although in many cases other navigational data, such as a D.R. position, will indicate which of the two loop positions gives the correct bearing of the transmitter, and which gives the false (reverse) bearing, it is often important to be able to differentiate directly between the two. This process is known as determining the *sense* of the bearing, and to do it the aerial must be modified so that only one minimum is obtained when the loop is rotated through 360° .

11. In practice, the aircraft loop and the aircraft's fixed aerial are both connected to the receiver, the pick-up from the fixed aerial being carefully adjusted to equal the maximum pick-up from the loop. When this condition is established, only one minimum will be heard during a complete rotation of the loop. It will be found that this single minimum now occurs when the loop is at an angle of 90° to its previous position, when it was used alone, i.e., it is now in line with the advancing wave. The minimum given by the loop and fixed aerial together is very coarse compared with the sharp minima given by the loop alone. Hence it cannot be used directly to determine a bearing, but simply indicates which of the two bearings given by the loop alone is correct.

The following is a description of the procedure of taking a bearing and determining its sense, using the General Purpose Receiver at present fitted in many types of aircraft.

Method of Taking Bearings with the G.P. Receiver

12. This procedure is carried out by the Wireless Operator, except in aircraft where the navigator is qualified to carry out W/T duties.

(i) The receiver is first tuned to the desired beacon with the aerial connecting switch at "Traffic." In this position the fixed aerial alone is connected to the receiver to obtain maximum pick-up.

(ii) The aerial switch is then put to "D/F," which disconnects the fixed aerial and connects the loop alone. The loop is now rotated manually until either one of the minima is reached, and the bearing is read off from the *black* "D/F" scale fitted to the loop spindle. The time of taking the bearing should, of course, be noted. The bearing obtained will be *relative to the heading of the aircraft*. The loop is

7. Lastly, consider the case where the loop lies at some intermediate angle to the advancing wave. The loop will now have the same effect as two components, one parallel with and the other at right-angles to the advancing wave. From what has been explained above it will be obvious that only the parallel component will be effective in conveying a current to the receiver, and the strength of the sound produced will depend on the comparative size of this component. (See Figure 7.)

8. The volume of sound produced will vary with the angle of inclination of the loop to the wave. Note also that there will be two maximum and two zero values of signal strength in 360° rotation of the loop. In ideal circumstances zero signal strength will be experienced at two sharply-defined positions of the loop. (See Figure 8.)

9. Provided that the electro-magnetic field remains horizontal, it will only affect the *vertical* members of the loop, the horizontal limbs

so mounted in the aircraft that the pointer indicates 0° and 180° when the loop is lying athwartships, i.e., with minima directly ahead and astern in each case. It is essential to know the exact True Course of the aircraft at the time of taking a loop reading because this has to be added to the loop reading to obtain the True Bearing. To simplify the task of finding the minimum, and of applying the True Course, the Navigator must tell the Pilot to steer a steady Course during the operation.

(iii) The aerial switch is now turned to "Sense," which connects both the loop and the fixed or trailing aerial to the receiver. The latter aerial through a variable resistance controlled by a knurled knob on the Sense Unit, marked "Increase," serves to adjust the amount of pick-up passed from the fixed aerial to the receiver. At the same time the loop is connected to the receiver through a Reversing Switch, the manipulation of which reverses the connections between the loop and the receiver. This obviates rotating the loop through 180° when determining sense. Having put the aerial switch to "Sense" the loop is rotated until the reading on the *red* "Sense" scale is the same as the original reading given on the *black* "D/F" scale. The two scales are offset by 90° to each other so that the loop is necessarily rotated through 90° between taking the D/F and Sense readings.

(iv) The Reversing Switch is now moved from "Reciprocal" (Reverse bearing) to "Bearing" and back again. If a weaker signal is obtained on "Bearing," the original bearing was correct. If however a weaker signal is obtained on "Reciprocal", the original bearing was $\pm 180^\circ$ out.

(v) Should no difference be observed between the volume of sound with the Reversing Switch in its two positions, the variable resistance control, marked "Increase", must be adjusted until there is a noticeable difference. In practice this adjustment is quickly made by trial and error.

To Summarise :

- (i) Set the aerial switch to "Traffic"; tune the receiver.
- (ii) Set the aerial switch to "D/F". Warn the Pilot to fly steadily and obtain the True Course from him. Rotate the loop to a minimum, and note the bearing on the *Black* Scale and the time.
- (iii) Set the aerial switch to "Sense." Rotate the loop to the same bearing on the *Red* scale.
- (iv) Manipulate the Reversing Switch. Note which position gives the minimum signal. If "Bearing", the original bearing was correct; if "Reciprocal" apply $\pm 180^\circ$ to the original bearing.
- (v) If necessary adjust the resistance control until a marked difference is obtained between "Reciprocal" and "Bearing."

Marconi Receiver and Loop—Operation

13. The operations for obtaining a D/F bearing or for homing when using a Marconi R 1155 receiver and loop are briefly as follows :—

- (i) The Receiver is tuned to the required transmitting station.
- (ii) A Visual Indicator shows when the loop is at right-angles to the direction of the transmitting station. The orientation of the loop relative to the aircraft's head is read off a dial near the Remote Control.
- (iii) Sense is obtained by reducing the loop reading or by turning the aircraft to the left. The Visual Indicator will move to the *Right* if the sense is *right* (i.e., if the loop reading is correct, or if the station lies ahead). If the Indicator moves to the *Left*, the correct loop reading is the reverse of that noted, or, alternatively, the aircraft must be turned through 180° in order to home.

14. It should be noted that the Track made good by an aircraft homing by loop tends to follow the arc of a Great Circle, the True direction of which usually changes at each meridian it crosses. When there is drift, it cannot easily be applied, even if it can be measured (unlikely in the circumstances). Consequently the homing aircraft will wander off the shortest route and approach the transmitting station from slightly down-wind and follow this rather longer route to its destination. In practice, homing is used over only short distances and these considerations can be completely ignored.

Quadrantal Error

15. When an incoming signal strikes an aircraft it gives rise to a number of re-radiated fields around the metallic portions of the aircraft's structure. These fields will each affect the aircraft D/F loop to a varying degree, depending on the strength of the interfering field around a certain part of the aircraft and its proximity to the D/F loop. The resultant error caused by all these interfering fields will vary

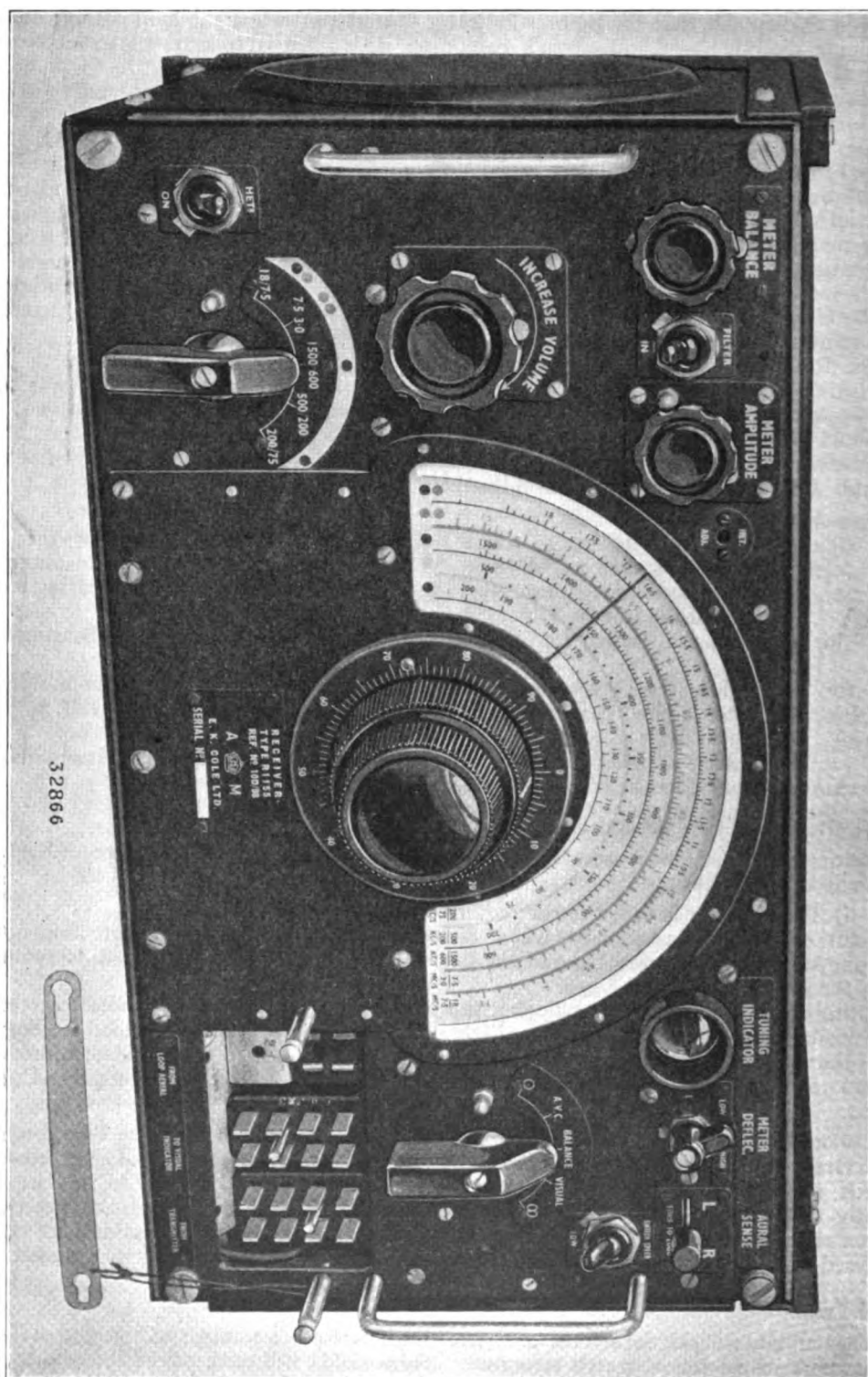


FIGURE 9. Marconi R.1155.

on different loop readings, and will be found to reach its maximum value roughly on the four quadrantal points. Hence it is termed *Quadrantal Error*. Different Quadrantal Errors are experienced at different frequencies, as the amount of re-radiation varies with the frequency.

16. Certain types of D/F loops—those mounted in stream-lined housings—are provided with a Quadrantal Error correction device, which is fitted in the stream-lined housing and surrounds the D/F loop. By adjusting the correction device, the local field is to a certain extent neutralised and Quadrantal Error reduced to $\pm 4^\circ$ approximately. In addition, the correction device sharpens the zero-signal. This adjustment and, similarly, the adjustment of the loop, with its associated controls and indicators, should be made only by skilled Signals personnel.

17. At installation and at subsequent periods of not more than 3 months, or when the aircraft structure is modified, the D/F equipment must be calibrated in order to ascertain the magnitude and distribution of Quadrantal Error. This may be determined by swinging the aircraft on various headings, using a transmitter as a source of signals whose True bearing is known, and noting the correction to be applied to each loop reading. The process may be compared with the determination of compass deviation and can indeed be done at the same time. The results may be plotted either in graphical form as shown in Figure 11, or alternatively as a numerical table using the Quadrantal Correction Card, R.A.F. Form 2026.

FRONT						BACK						
0	0	120	- 9	240	+ 7	RA.F. FORM 2026 QUADRANTAL CORRECTION CARD AIRCRAFT TYPE:- AIRCRAFT No:- D.F. LOOP TYPE:- D.F. LOOP SERIAL No:- CHECKED:- DATE:- <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left;">TRANSMITTER</th> <th style="text-align: left;">FREQUENCY</th> </tr> </thead> <tbody> <tr> <td style="height: 20px;"></td> <td></td> </tr> <tr> <td style="height: 20px;"></td> <td></td> </tr> </tbody> </table> INITIALS:- RANK :-	TRANSMITTER	FREQUENCY				
TRANSMITTER	FREQUENCY											
10	+ 6	130	- 9	250	+ 5							
20	+ 9	140	- 10	260	+ 3							
30	+ 10	150	- 10	270	0							
40	+ 9	160	- 6	280	- 3							
50	+ 9	170	- 6	290	- 5							
60	+ 7	180	0	300	- 7							
70	+ 2	190	+ 8	310	- 9							
80	+ 2	200	+ 8	320	- 10							
90	0	210	+ 10	330	- 10							
100	- 3	220	+ 10	340	- 9							
110	- 5	230	+ 9	350	- 7							

FIGURE 10. Quadrantal Correction Card.

It should be noted that it is most desirable to swing each individual aircraft separately. Results of some accuracy may sometimes be obtained by using the standard correction curve for the type of aircraft concerned, but it is not unusual for the curve of any individual aircraft to depart widely from the standard curve for that type of aircraft.

18. The quadrantal correction is always recorded or plotted against the *loop reading* and *NOT* against the aircraft's Course. In the same way, when taking a bearing with the loop, the quadrantal correction for the particular *loop reading* is applied directly to that loop reading, before applying the aircraft's Course, to obtain a proper bearing.

Examples of Quadrantal Correction :

19. A Navigator in an aircraft on a Course of 275° M obtains a loop reading of 310° (after sense determination) on a given Beacon. At the moment the loop reading was taken, the great circle bearing of the transmitter from the aircraft is known to be 218° T. The Variation is 11° W. What is the Quadrantal Correction to be applied ?

Magnetic Course of Aircraft	...	...	...	275°
Variation (W)	...	...	...	$- 11^{\circ}$ " <i>Magnetic Best</i> "
True Course of Aircraft	...	...	...	264°(a)
Loop Reading of Beacon	...	...	...	310°(b)
Sum of (a) and (b) above	...	...	...	574°
Reject 360° , if necessary	...	...	...	-360°
G.C. Bearing of Beacon by Loop	...	...	...	214°
Known True G.C. Bearing of Beacon	...	...	...	218°
∴ Quadrantal Correction for reading of 310°	...	...	...	$+4^{\circ}$ " <i>ADD</i> "

20. An aircraft is flying on a Co. of 146° C. The Navigator takes a loop reading of 074° of a certain Beacon.

Deviation $+ 3^{\circ}$ (E) ; Variation 10° W. Quadrantal correction for a reading of 074° , SUBTRACT 3° . What is the True Great Circle Bearing of the Beacon from the aircraft ?

Compass Course	...	...	...	146°
Deviation (E)	...	...	...	$+ 3^{\circ}$ " <i>Compass Least</i> "
Magnetic Course	...	...	...	149°
Variation (W)	...	...	...	$- 10^{\circ}$ " <i>Magnetic Best</i> "
True Course	...	...	...	139°(a)
Uncorrected Loop Reading	...	...	...	074°
Quadrantal Correction	...	...	...	$- 3^{\circ}$
Corrected Loop Reading	...	...	...	071°(b)
∴ True G.C. Bearing of Beacon from Aircraft	...	...	...	210° T..... (a) + (b)

Calibration of Aircraft Loops

21. The sequence of operations detailed below for calibrating an aircraft loop gives a simple and comparatively quick method of determining Quadrantal Correction for all loop readings. It is not, however, a system which may be rigidly applied to all aircraft. In some few cases it may be unnecessary to swing individual aircraft, since the standard calibration for the aircraft type may give sufficient accuracy. Again, large and heavy aircraft are extremely inconvenient to swing on numerous headings, especially if setting them up in "flying position" involves much lifting of the tail. It will often be found simpler to swing such aircraft in flight. Fuller details are given in the Signals Manual, Vol. I, Section 6, Chapter 10 (A.P. 1186). It should not be forgotten that the calibration of an aircraft loop on one frequency is not strictly applicable to another frequency.

Notes for Calibrating an Aircraft Loop on the Ground

22.—(i) Select an open, level spot away from sources of electrical or magnetic interference. With the aid of Signals personnel, choose a suitable transmitter, within the frequency band to which the calibration is to apply, and, if possible, at a distance of 50 to 100 miles from the site of swinging.

Make sure in any case that the transmitter chosen will remain in operation during the whole process of the swing. Measure from a map or calculate the True Great Circle bearing of the transmitting station from the aircraft.

(ii) Since the accuracy of the swing depends on the aircraft compass, it is essential that the latter has itself recently been calibrated with all equipment in place on the aircraft, including the D/F loop, a point which is sometimes overlooked when swinging a D/F loop on first installation. It is a sound plan to check each heading with a landing compass, if swinging on the ground.

(iii) Set up the aircraft, as nearly as possible in flying position, so that the loop lies in its correct plane, on headings approximately at 10° intervals all round the compass. This is impossible with heavy aircraft and *provided the loop is not screened by the nose* it may be swung fairly satisfactorily tail down. Exact adherence to these intervals is not necessary, and it is a waste of time to "juggle" the Course exactly to a multiple of 10° ; any point within $\pm 2^\circ$ will do as well. On each heading note:—

- (a) the compass heading;
- (b) loop reading, by minimum, of the transmitter; and
- (c) the compass deviation.

(iv) The readings taken may conveniently be tabulated as in the example below. The compass heading is corrected to give the True heading. This is added to the loop reading to give the True great circle bearing of the transmitter by D/F. Comparison of the latter with the known True great circle bearing of the transmitter (found from the map or by calculation) will give the Quadrantal Corrections to be applied to each loop reading.

Example:—

23. The following table illustrates the calibration of a loop in an aircraft, whose compass is subject to a Variation of 10° W, and to the Deviations shown in column (b).

(a) Compass Heading	(b) Deviation	(c) Variation	(d) True Heading (a + b + c)	(e) Loop Reading	(f) True Bearing of Transmitter by D/F (d + e)	(g) True Bearing of Transmitter from Map	(h) Quadrantal Correction (g - f)
009	+1	-10	000	331	331	321	-10
032	0	-10	022	307	329	321	-8
056	-1	-10	045	278	323	321	-2
076	-2	-10	064	253	317	321	+4
094	-2	-10	082	230	312	321	+9
101	-1	-10	090	221	311	321	+10
108	0	-10	098	213	311	321	+10
125	+2	-10	117	197	314	321	+7
142	+4	-10	136	184	320	321	+1
163	+4	-10	157	170	327	321	-6
188	+2	-10	180	151	331	321	-10
213	-1	-10	202	128	330	321	-9
237	-3	-10	224	099	323	321	-2
255	-3	-10	242	074	316	321	+5
275	-3	-10	262	050	312	321	+9
283	-3	-10	270	041	311	321	+10
291	-2	-10	279	032	311	321	+10
307	-1	-10	296	017	313	321	+8
324	+1	-10	315	004	319	321	+2
346	+1	-10	337	351	328	321	-7
000	+1	-10	351	339	330	321	-9

24. The corrections are conveniently plotted as a graph, to assist interpolation between readings. Form 2026, Quadrantal Correction Card, is illustrated in Figure 10, and a graph based upon it, in Figure 11. When the corrections are small, it is most convenient to construct a *critical table* (See Chapter VIII).

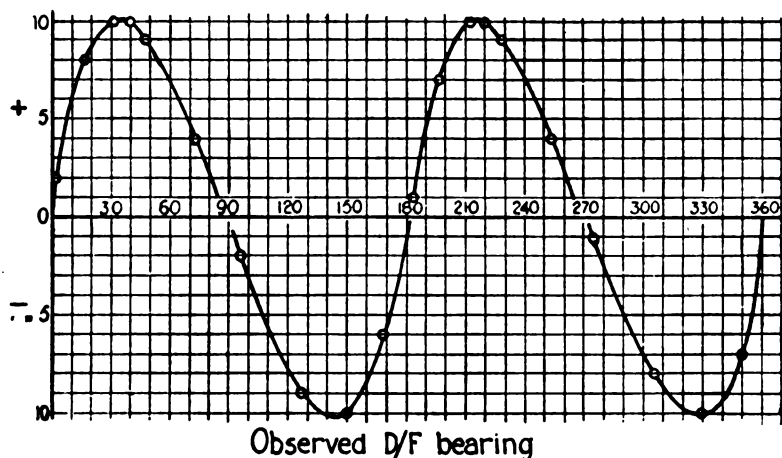


FIGURE 11. Quadrantal Correction Curve.

Should the Quadrantal Corrections prove, on inspection, to be predominantly positive, or negative, the curve of Corrections against loop readings will not be symmetrical about the zero line. A balance may be effected by offsetting the pointer of the loop a few degrees in the required direction. This operation may be likened to that for correcting co-efficient A in a compass, which in this case is due to misalignment of the loop housing, or of the loop to the housing, or of the remote-control Visual Indicator to the loop-shaft. Hence it is most important to calibrate the loop rather than rely upon the standard corrections.

Calibrating an Aircraft Loop in the Air

25. Because of the difficulty of accurate pin-pointing in flight and the consequent inability to determine the actual great circle bearings, with which to compare the bearings obtained by loop, swinging an aircraft in the air requires a pre-arranged plan. The principles explained in paragraph 22 above should be carefully adhered to, while the aircraft is flown on steady Courses over a selected and distinctive landmark (such as the centre of an aerodrome) from which it is possible to measure on a map the True great circle bearing of a suitable, distant transmitter. The loop operator holds the minimum signal as the landmark is approached, and he takes the reading of the loop at the moment when the aircraft is directly over the landmark, the Pilot noting the compass Course at the same instant. Only short runs need be made, the final calculations and adjustments being done when back on the ground.

Night Effect on D/F Loops

26. A transmitting station propagates two rays, the direct, or ground, ray and the indirect ray which is reflected from a region in the upper atmosphere known as the Heaviside Layer. The direction of a transmitter may be found without difficulty when using the ray travelling parallel to the Earth's surface, since its magnetic field is horizontal.

27. In its reflection by the Heaviside Layer, the structure of the indirect ray is considerably modified, and electro-magnetic forces are produced along the horizontal limbs of the loop either instead of, or as well as, those produced along the vertical limbs. These E.M.F.s cause a signal to be heard at a reading of the loop where a zero should be obtained. Thus an error is introduced into the determination of the transmitter's direction.

28. The indirect ray is comparatively weak when the loop is situated near a transmitter and hence good bearings can be obtained. On Medium Frequencies, as used on aircraft D/F loops, the indirect ray is relatively weak during daylight hours, and good bearings are obtainable. At night, however, the indirect ray becomes more pronounced and is a larger proportion of the total signal received; hence the name "*night effect*."

29. The distance from an M.F. transmitter where night effect is encountered can only be given approximately, because the effect varies not only during the periods of sunrise and sunset and throughout the night, but also from season to season. As a general rule it becomes noticeable at distances exceeding 100 miles from such a transmitter. When the aircraft is flying high, the effect is less than when it is flying low.

30. Between sunset and sunrise, when more than 100 miles from a transmitter, accurate bearings should not be expected consistently from aircraft D/F loops. Bearings taken under these conditions will be only satisfactory for "homing," if checked from time to time, though they will be most unsteady. Bearings taken at night on stations at distances over 100 miles will not be sufficiently accurate or reliable for fixing position. They become displaced and swing rapidly, while the minima may be blurred and accompanied by "fading" of signals.

Coastal Refraction

31. It is usually assumed that the radio wave arrives at the Receiver by the shortest possible path from the transmitter, but in practice the wave may be deflected in many ways, as for example, when it passes from sea to land or land to sea across a coast line. The change of direction from this cause is called *Coastal Refraction*, and gives rise to errors in D/F which are most marked when the wave crosses the coast line at an acute angle. Ground D/F stations are calibrated so that in practice the refraction of radio waves received from different directions is known and can be allowed for. Loop bearings obtained in aircraft cannot be corrected in this way.

Selection of Stations for Use with Loop

32. At all times considerable care should be exercised by the Navigator or Wireless Operator in selecting stations from which to take bearings with an aircraft D/F loop. Several stations often operate on the same frequency, as in the case of Broadcasting, the resultant of the several transmissions being received on the loop and proving most misleading. Only those stations detailed by the Signal Officer should be used. At the same time, it is important to obtain bearings that cut one another at angles larger than 30° . If only a small angle is formed by position lines, the resulting fix can never be relied upon for navigational purposes. This aspect of fixing has been examined in Chapter VI. The angle of the "base line" is therefore important to consider when estimating the reliability of a fix.

Outline of Ground D/F

33. All Royal Air Force Ground D/F Stations are used for fixing the position of aircraft on request and for homing aircraft. They fall into three classes according to their *frequency*, as follows :—

- (i) Medium Frequency (M.F.), 100–1,000 kc/s ;
- (ii) High Frequency (H.F.), 2,500–10,000 kc/s ;
- (iii) Very High Frequency (V.H.F.), 100–150 mc/s.

M.F. D/F Stations

34. In the Medium Frequency two types of station are used in the Royal Air Force, namely, Loop and Adcock.

(i) Loops

There are only a few loop-type stations in use, as they suffer from night effect. The bearings may be sharp and yet have night errors up to 90° . These errors, however, decrease as the wavelength increases and as the range decreases. At ranges of only 30–50 miles they are quite reliable.

(ii) Adcocks

Night effect is caused by the horizontal limbs of the loop picking up signals from the Heaviside Layer. It can be eliminated, as in the Adcock system, by using aerials consisting of vertical limbs only.

35. To obtain a fix, two or more M.F. stations suitably placed and connected by telephone or W/T are used. The D/F stations receiving the aircraft signals obtain bearings and communicate them to the control station where they are plotted upon a map. The result is then transmitted to the aircraft. The average time to obtain a fix should not exceed three minutes, unless there is excessive traffic, as when a large number of aircraft are clamouring for fixes at once. Details of the organisation can be found in C.D.216.

H.F. D/F Stations (Flying Control)

36. H.F. D/F stations are similar to the M.F. D/F Stations, but are smaller in construction. The chief use made of the H.F. D/F is for *homing*, and for this purpose they have proved to be very reliable. Every Bomber Station has its own H.F. D/F station to give homing bearings. The organisation of Flying Control Stations can be found in C.D. 216.

37. The maximum distance at which they should be used is 100 miles. (There is, however, a long-range H.F. fixing service which works beyond the "skip" distance, and consists of Cathode Ray D/F stations which cannot be discussed in this Manual.) The range of H.F. stations is very largely dependent upon the height of the aircraft.

38. The only H.F. fixing service in use is for Fighter aircraft within the Sectors laid down for their operation. Three stations work together like the M.F. D/F fixing service, but owing to their reduced range they are only about 30 miles apart at present.

V.H.F. D/F Stations

39. A V.H.F. D/F organisation, at present confined to Fighter Command, is replacing H.F. D/F fixing. Further details of this organisation can be found in the relevant Signals publications.

Range

40. In considering range it is necessary to take into account certain facts about the propagation of wireless waves, which travel by different paths to a distant receiver according to their frequency. An earth-bound wave travels from the transmitter to the receiver, spending its energy upon whatever ground or water is in its path and so gradually becoming weaker. The attenuation of a ground wave increases rapidly with its frequency, and in the case of high frequency waves, it is great enough to damp out entirely the earth-bound wave within 30–50 miles of the transmitter, if the latter is on the ground. When the transmitter is in the air, the ground wave travels about as far as the visible horizon.

41. The M.F. D/F organization will normally give a range in this country of 150–300 miles from aircraft to D/F station. The range will be greatest when the wave travels over sea-water and least when the path is over desert or mountains. It is reduced by bad "atmospherics" or by interfering signals designed to mask the aircraft signals at the D/F stations. Medium frequency waves do not gain much in range if the aircraft is taken higher, as their attenuation over land and sea is not great.

42. H.F. waves, on the other hand, spend themselves so rapidly on the ground that to get good results it is very important to fly as high as possible and to avoid having any intervening land at all. A peculiar property of such waves is that although they may disappear quickly on an overland path, they also travel up to the sky and are reflected from conducting layers high up, so that after a certain blank or "*skip distance*" they re-appear on the Earth as strong signals once more. Outside the skip distance the bearings obtained from these signals are invariably unreliable. When the aircraft is flying low, e.g., 1,500 ft., not only will the bearings be poor but the range may only be in the order of 25 miles, depending on the type of country that is between the D/F station and the aircraft. A safe distance to take for range is about 10 miles per 1,000 ft. above the ground for Fighters, and 20 miles for Bombers (more power).

43. The range of V.H.F. is *optical*, i.e., it depends largely on the height of the aircraft above the ground. Reference to *A.N. Table IX* (A.P. 1618), giving the distance to the sea horizon for various heights, serves as a rough guide to what can be expected.

General Conclusions

44. (i) All D/F may be subject to a certain amount of enemy interference, and the organization of D/F facilities has therefore to be kept secret. Navigators must ensure that all details of call-signs, frequencies and locations, taken into the air, are *up to date*.

(ii) The reliability of D/F depends upon the distance from the station, the height, the kind of intervening country and the prevailing atmospheric conditions.

(iii) Congestion may occur when asking for D/F bearings from ground stations, since each station can only handle one aircraft at a time. When flying conditions are bad and D/F assistance is in great demand, serious delay may be unavoidable.

(iv) When using the aircraft loop, bearings can be obtained at any time without causing congestion. Reliability of the bearings obtained is often doubtful, and at extreme range (300 miles) their plotting

as position lines may be complicated. The sense of a D/F bearing should always be checked against the bearing to be expected from general considerations. A steady Course is essential for obtaining accuracy with a loop.

(v) Good fixes can only be obtained when the Base line, between the stations used, subtends a reasonably large angle ; 30° must be regarded as an absolute minimum.

(vi) The failure of the aircraft's W/T, due to a variety of reasons, cuts the Navigator off completely from all D/F facilities.

(vii) It cannot be too strongly emphasized that D/F is only an AID to Navigation. Used cautiously and always supported by a background of other observations, it can be a valuable asset to assist, but *never* to replace D.R. Navigation.

CHAPTER X

TACTICAL NAVIGATION

" You may call it ' nonsense ' if you like," she said, " but I've heard nonsense compared with which that would be as sensible as a dictionary ! "

—ALICE THROUGH THE LOOKING GLASS.

Introduction

1. The process of solving velocity problems by means of vector triangles can be applied to many navigational problems of a purely tactical nature. Some of the problems in this Chapter are of much less practical value than others, but all provide useful quickening exercises in plotting, and will help the Air Navigator to develop a mature grasp of the scope of his subject.

Course to Make Good the Reverse Track

2. If for any reason it is desired to make good the reverse Track to that being followed, the Navigator should immediately apply the following rule :—

To the reverse of the outward Course apply PLUS twice drift, if this has been to starboard, or, MINUS twice drift, if this has been to port.

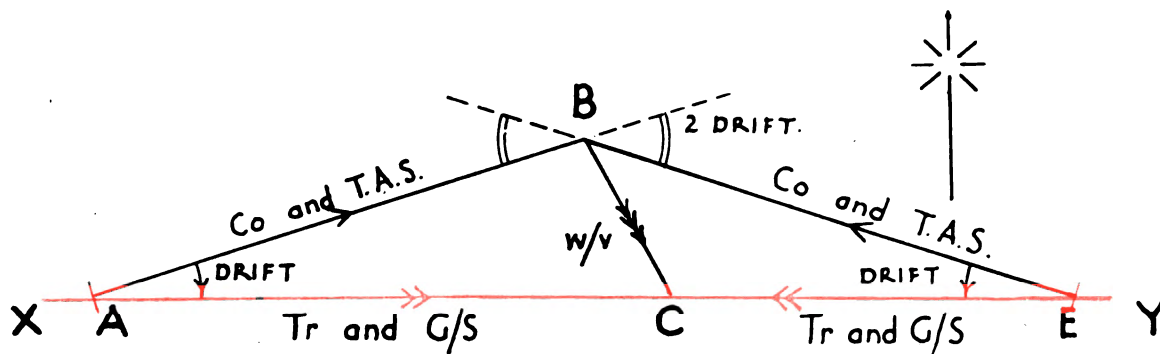


FIGURE 1. Course for Reverse Track.

Proof :—

3. In Figure 1, C is any point to which reverse Tracks XC and YC are drawn. XCY is therefore a straight line.

BC is the Wind vector, and AB, EB represent the Courses at a constant True Airspeed to make good Tracks XC and YC respectively.

Since AB equals EB, triangle ABE is isoscles, and angle BAC equals angle BEC.

That is, the angles of drift are equal, though opposite in NAME.

It follows that the Course to make good one Track differs from the reverse of the Course (dotted line in Figure 1) to make good the reverse Track by twice the angle of drift, and that this difference is additive or subtractive according to which Course is under consideration.

The Fixed Square Search

4 When the destination does not show up on E.T.A., in certain conditions of reduced visibility and in the absence of "homings" facilities, it may be advisable to carry out a systematic search. Under the strain of the moment any scheme but the simplest will be rejected, yet it is essential for the Navigator to be able to continue his D.R. Navigation during the search, and at the same time, to ensure finding what is sought. The following search is easily applied and, providing the Wind used is reasonably accurate, the object of the search cannot be missed.

5. The Navigator decides the maximum visibility distance, at which the object of the search may be seen and recognised, allowing for a margin of safety.

The aircraft is steered to make good Tracks at right-angles to each other, and at a distance apart not exceeding twice visibility distance (2V). This is arranged by flying along the first Track a distance equal to 2V, and increasing the Track length by 2V on every *alternate* Track. (See Figure 2.)

6. In order to avoid pre-computing the Courses or making last-minute calculations, the Tracks are best arranged up, down and across the Wind. It will be necessary to calculate the drift and Ground Speed on only *one* cross-wind Track, since the Ground Speed and drift either way are the same (though the drift is of opposite sign). Up- or down-wind Tracks will have no drift, and the Ground Speed is simple True Airspeed minus or plus Wind Speed respectively.

It may be difficult to look in the direction of the Sun in certain conditions of visibility. In this event, the Tracks may be arranged at 45° to the Sun's azimuth. At night it may be best to look up-Moon, and the Tracks should then be arranged accordingly.

In any event, the first Track of the search should be in that direction most nearly a continuation of the original Track of the aircraft. This avoids a large alteration of Course at the beginning of the search, thereby disturbing the aircraft instruments less.

Example :

7. A Navigator in an aircraft returning to a satellite landing ground on a Track of 305° T, fails to locate his destination on E.T.A. 03.00 hours. The True Airspeed is 200 k. The Wind Velocity is 270°/20 k, and the visibility distance is estimated to be 3 n.m.

The Navigator institutes a square search (See Figure 2), and his log reads as follows :—

Time	Reqd. True Track	Distance Run	True Course	Magnetic Course	Observation
03.00.00	270	—	270	282	Start search S/c Var. 12° W. Vis. 3 n. m. G/S 180 k
03.02.00	180	6	186	198	A/c G/S 198 k Drift 6° P.
03.03.48	090	6	090	102	A/c G/S 220 k
03.07.00	000	12	354	006	A/c G/S 198k Drift 6° S.
03.10.40	270	12	270	282	A/c G/S 180 k
03.12.00	—	4	—	—	Landing ground.

8. This method of applying a square search also has the advantage that the Tracks can be plotted well in advance of the operation, since they take but a few moments to draw.

When it is a question of fixing the position of an object whose whereabouts are only vaguely known, the search should be started from a known nearby position, and the position of the object determined subsequently by plotting.

The Moving or Relative Square Search

9. When looking for a moving object such as a ship or part of a fleet, the search should be arranged so that the Tracks remain square *relative to the moving object*. Otherwise it is possible that the object might move out of the limits of vision while the Navigator's back is turned.

It is necessary to know the extent of the object's movement. Given this additional data, the relative Wind (see Chapter V, paragraph 49), should be calculated. If the Tracks of the aircraft are arranged up, down and across the *relative Wind*, the square search is made to move bodily with the object.

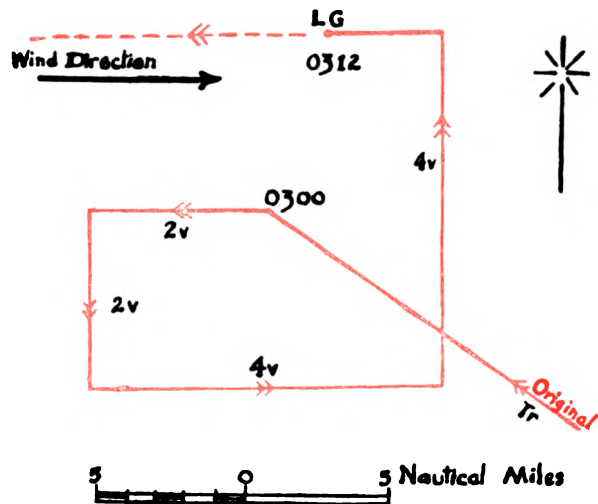


FIGURE 2. The Fixed Square Search.

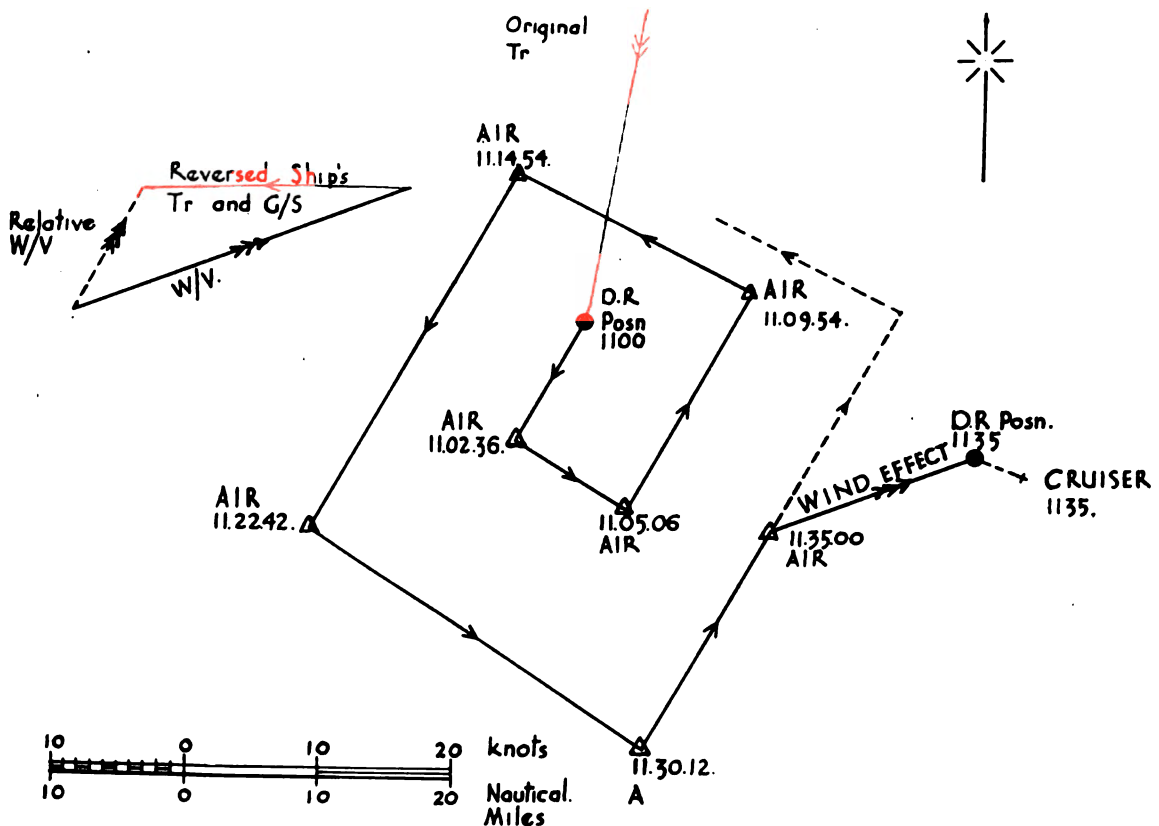


FIGURE 3. The Moving or Relative Square Search.

Naturally the calculations are slightly complicated, since the actual Tracks of the aircraft can only be deduced by applying the true Wind to the Courses flown. Consequently it is most convenient to keep an air plot of the Courses and air distances flown, applying the Wind Effect at any moment to determine the ground position.

Example :—

10. An aircraft, cruising at a True Airspeed of 240 k, is maintaining a Track of 188° T, until 11.00 hours, to intercept an enemy cruiser known to be proceeding at 20 k in a direction of 090° T. The Wind in the area of operation is $250^\circ/27$ k. The visibility distance is considered to be 5 n.m.

Following the procedure laid down in Chapter V, paragraph 49, the relative Wind is found to be $210^\circ/11$ k. (See inset to Figure 3.) The successive Courses are calculated for *relative* Tracks using the *relative* Wind. The results are tabulated below :—

Relative Track ° T	Relative G/S k	Relative Dist. n.m.	Time mins.	Air Dist. n.m.	Course ° T	D.R. Track ° T	D.R. G/S k	D.R. Dist. n.m.
210	229	10	2.6	10.4	210	205	220	9.5
120	239	10	2.5	10.0	123	118	256	10.6
030	251	20	4.8	19.2	030	034	260	21.0
300	239	20	5.0	20.0	297	302	222	18.5
210	229	30	7.8	31.2	210	205	220	28.5
120	239	30	7.5	30.0	123	118	256	31.8
030	251	40	9.6	38.4	030	034	260	42.0

and so on.

It is not necessary to calculate the last three columns shown, as an air plot should be kept from the start of the search.

11. The search is illustrated in Figure 3. The Cruiser is sighted at 11.35 hours, bearing 110° T, distant 4 n.m. from the aircraft. Its position is therefore found by laying off the Wind Effect from the air position of the aircraft at 11.35, and laying off the range and bearing from this D.R. position, as illustrated.

Modified Parallel Track Search

12. When more than one aircraft are engaged in the search for a destination or target, the square search method becomes too cumbersome to be practical, particularly where large formations are involved. In order to minimise the danger of collision and at the same time, to make full use of the searching power and tactical support of the aircraft, the whole formation may be used to sweep any particular area in which it is thought the object of the search may be situated.

Upon reaching the limits of the search area individual aircraft are ordered to leave the formation on parallel Tracks and at equal time-intervals so that they will remain in visual contact with each other. When all the aircraft have changed Course, a sweep is made across the width of the search area. If the first sweep is unsuccessful, the aircraft are turned in the same order as before and at the same time-intervals. It will then be possible to assume the original formation and proceed further along the search area preparatory to making a similar sweep in the reverse direction.

13. A typical sweep is illustrated in Figure 4, where three aircraft were operating together. The search area was in this case approached from the S.W. Visibility was 5 n.m.

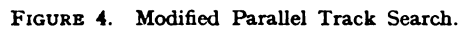
Upon nearing the area of search, the aircraft were "peeled off" on parallel Tracks at 1-minute intervals, it being calculated that when following these Tracks, the distance between the aircraft would not exceed 5 n.m., and visual contact would thus be maintained.

The positions of the aircraft when all were turned on the first sweep are shown as A, B and C.

When it was calculated that A had passed beyond the search area, he was ordered to turn and fly along the area boundary, as shown in Figure 4.

Aircraft B and C turned 1 and 2 minutes after A respectively, and all three aircraft proceeded together to D, which is a distance equal to twice the visibility distance from the sweep-Track of aircraft C ($2V = 10$ n.m. in this case). The procedure was then repeated in the reverse direction.

14. The best results are achieved if the Navigation is left in the hands of the leading aircraft, times and Courses to steer being passed to the other members of the formation individually. If the inter-communication is only visual, difficulties will arise on account of the delay in communicating detailed



Problems Involving Four Velocities

The beginner should understand the theory of Relative Velocity explained in Chapter II before proceeding with the following problems.

Patrolling a Constant Bearing

The diagram shows a velocity triangle with vertices C, D, and W. Point C is on the horizontal axis X-Y, and point D is also on the horizontal axis X-Y to the right of C. Point W is above the horizontal axis. A vertical line with a star at the bottom passes through C. A dashed line connects W and D, with an angle of 115° marked between the horizontal axis and this dashed line. A red arrow labeled 'Convoy's Tr.' points from D towards W. A red arrow labeled 'Tr. OUT' points from W towards C. A red arrow labeled 'Tr. BACK' points from W towards D. A red arrow labeled 'Co. OUT' points from C towards W. A red arrow labeled 'Co. BACK' points from D towards W. Below the diagram is a scale bar with markings at 0, 25, 50, 100, and 200, followed by the word 'Knots'.

FIGURE 5. Patrolling a Constant Bearing.

Example :—

17. A Navigator in an aircraft operating with a convoy is ordered to carry out a patrol on a constant bearing of 125° to starboard of the mean line of advance of a convoy, a direction from which air attack is anticipated.

The convoy's mean Track is 145° T. at a Ground Speed of 20k.

The aircraft cruises at a True Airspeed of 200 k.

The Wind Velocity is $110^\circ/25$ k.

To find :— (i) The Courses to steer, out and back.
(ii) The Speeds of opening and closing.
(iii) The Tracks and Ground Speeds of the aircraft.

Solution :—

18. Draw BA to represent in length and direction the Ground Speed and mean Track of the convoy reversed.

From A draw the Wind Vector AW, down-wind.

Through B draw the requisite line of constant bearing, YBX a direction of $(145^\circ + 125^\circ =) 270^\circ$ T.

With centre W and radius the aircraft's True Airspeed to scale, strike arcs on BX and BY at C and D.

Then :— WC is the Course out, 263° T.
WD is the Course back, 097° T.
BC is the Speed of opening, 233k.
BD is the Speed of closing, 164 k.
AC is the Track and Ground Speed out, 266° T, 222k respectively.
AD is the Track and Ground Speed back, 093° T, 175 k respectively.

Keeping Station

19. An aircraft may be ordered to patrol about a given position relative to a moving object. In this case the *distance* from the object and the line of constant bearing will be detailed. Clearly the aircraft cannot so reduce its Airspeed that, having arrived at its patrol station, it will be able to maintain its relative position by flying on one Course only. In order to "keep station" it will have to fly to and fro between certain specified limits.

Provided the aircraft flies on the requisite Course out or home, the line of bearing will remain constant. If the Course out is so regulated in time with the Course back that the aircraft is flown an equal distance on either side of the ordered station, the patrol may be carried out at normal Airspeeds.

Example :—

20. An aircraft flying at 200 k is ordered to keep station on a convoy proceeding at 15 k in a direction of 005° T. The W/V is $305^\circ/25$ k.

The aircraft must fly within 5 n.m. of a position 20 n.m. on a constant bearing of 270° T from the convoy.

To find :— (i) The Course out to the station.
(ii) The Course back to the convoy.
(iii) The action necessary to maintain station.

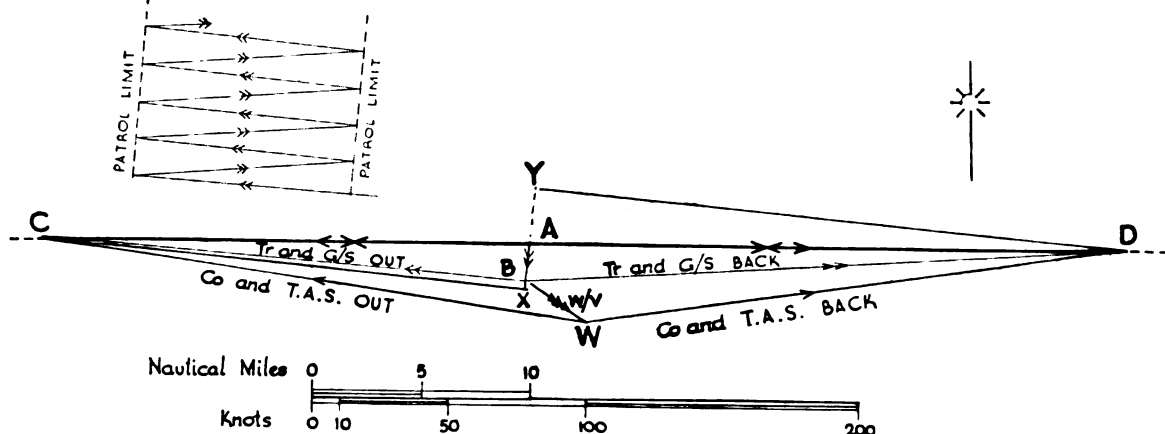


FIGURE 6. Keeping Station.

21. Figure 6 shows the familiar constant bearing diagram, in which

AB	represents	185°/15 k, the convoy's reversed Track and G/S ;
BW	„	125°/25 k, the Wind Velocity, down-wind ;
WC	„	278°/200 k, the Course and T.A.S. out to the station.....(i)
BC	„	274°/176 k, the Track and G/S out to the station ;
WD	„	082°/200 k, the Course and T.A.S. back to the convoy.....(ii)
BD	„	086°/219 k, the Track and G/S back to the convoy ;
CAD	„	the line of constant bearing.

and (10 n.m. at 217 k =) 3 minutes, on a Course of 082° T.

The progress of the aircraft will be as illustrated inset in Figure 6.

22. A variation of the preceding problem arises when an aircraft that is keeping station on a moving datum, such as a convoy, is ordered to take up another station relative to the same moving datum. The principle of solution is identical.

23. At 10.00 hours an aircraft whose True Airspeed is 250 k is in a position 50 n.m. on a bearing of 030° T from a convoy. The convoy is travelling on a Course (Track) of 275° T at 15 k. The Wind is 316°/20 k. The aircraft is ordered to take up patrol duties at a point on a constant bearing of 60° to starboard of the convoy and 20 n.m. from it.

To find :—

- (i) The Course to steer for the new station.
- (ii) The Track and Ground Speed to the new station.
- (iii) The estimated time of arrival at the new station.

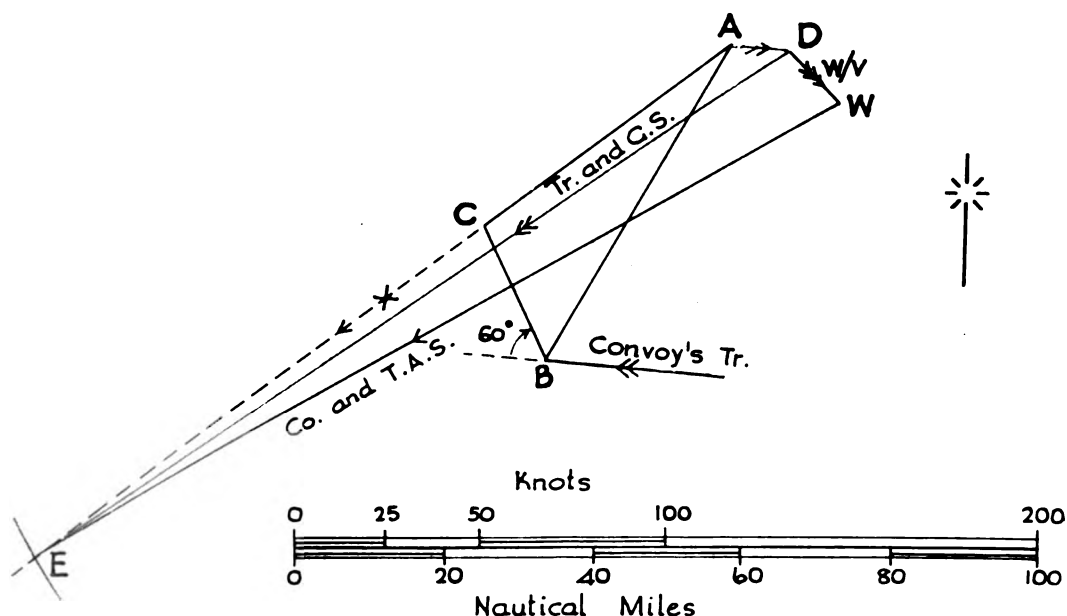


FIGURE 7. Changing Station.

Solution :—

24. Plot the positions of aircraft and convoy at 10.00 hours, A and B respectively.

Plot the new station of the aircraft at C, as a distance of 20 n.m. on a bearing of $(275^\circ + 60^\circ =) 335^\circ$ T from B.

Join AC, which measures 42 n.m. The aircraft must close this distance relative to the convoy. AC is therefore a line of constant bearing.

Construct on AC a constant bearing diagram. That is, from A lay off the convoy's reversed Track and Ground Speed, AD; and from D lay off the Wind Vector, down-wind, DW.

With centre W, and radius the True Airspeed to scale, strike an arc at E on AC (produced if necessary).

Then WE is the Course to steer, 240° T.....(i)

DE is the Track and Ground Speed to the new station, 236° T, 246 k respectively.....(ii)

AE is the speed of closing, 234 k.

The time taken will be AC (42 n.m.) at 234 k, 11 minutes approximately.

Therefore 10.11 hours is the estimated time of arrival.....(iii)

Interception

25. In its simplest form, the problem of interception may require the solution of only one triangle of velocities, namely that triangle determining the relative velocity of the participants. Needless to say, this simple case rarely arises in practice, but a thorough understanding of the principle involved is essential if the complex problems that occur more often are to be solved easily.

The Fundamental Case

26. An aircraft in position A at 11.00 hours has a True Airspeed of 300 k. At the same time another aircraft is at B, 50 n.m. on a bearing of 045° T from A. The second aircraft has a True Airspeed of 200 k and is on a Course of 270° T.

What Course should be set from A, and how long will it take to intercept the second aircraft ?

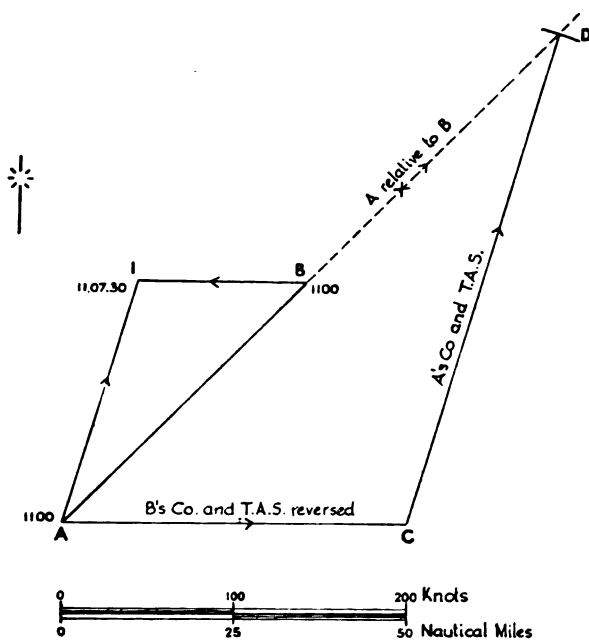


FIGURE 8. Interception, the Fundamental Case.

The interception will, therefore, take place after (50 n.m. at 405 k =) $7\frac{1}{2}$ minutes, i.e., at 11.07.30 hours.

At 11.07.30 hours the two aircraft will be at I, an air position where the two Courses from A and B meet.

27. The quickest interception will be that in which the distance AB is closed at maximum speed. This, for any given Airspeed, will be obtained if the bearing of the second aircraft from the first is maintained throughout the flight. In other words, the problem is solved by drawing a constant bearing diagram with the given data. This can be done in two ways according to which aircraft's relative velocity is considered (the one being the reverse of the other).

Take the velocity of the first aircraft relative to the second. It is the resultant of the velocity of the first aircraft and the reverse velocity of the second. The direction of this resultant is known, namely 045° T.

Having joined AB, lay off AC to represent the reverse velocity of the second aircraft. With centre C and radius the True Airspeed of the first aircraft, cut an arc at D on AB (produced if necessary).

Then CD is the direction of the velocity of the first aircraft, i.e., the Course to intercept, 017° T.

AD is the speed of the resultant relative velocity, i.e., the speed of closing, 405 k.

Intercepting an Aircraft whose Position, Track and Ground Speed are Known

28. Observation of an enemy aircraft from the ground usually provides a knowledge of its Track and Ground Speed. To make an interception, its Course and True Airspeed have to be deduced by applying a Wind Velocity that is either known, or assumed, to be affecting the aircraft. If nothing is known of the Wind in the locality of the enemy aircraft, it must be assumed to be the same as that experienced at the place of departure.

Example :—

29. A bomber aircraft, X, is known to be making good a Track of 120° T at 232 k and at the moment a fighter, Y, leaves to intercept it, it is 250 n.m. away on a bearing of 025° T. The fighter's True Airspeed is 340 k. The mean Wind Velocity for the area at height of operations is known to be $320^\circ/30$ k.

To find :— (i) The fighter's Course to intercept.
(ii) The geographic point of interception. (G.P.I.).
(iii) The estimated time of interception. (E.T.I.).

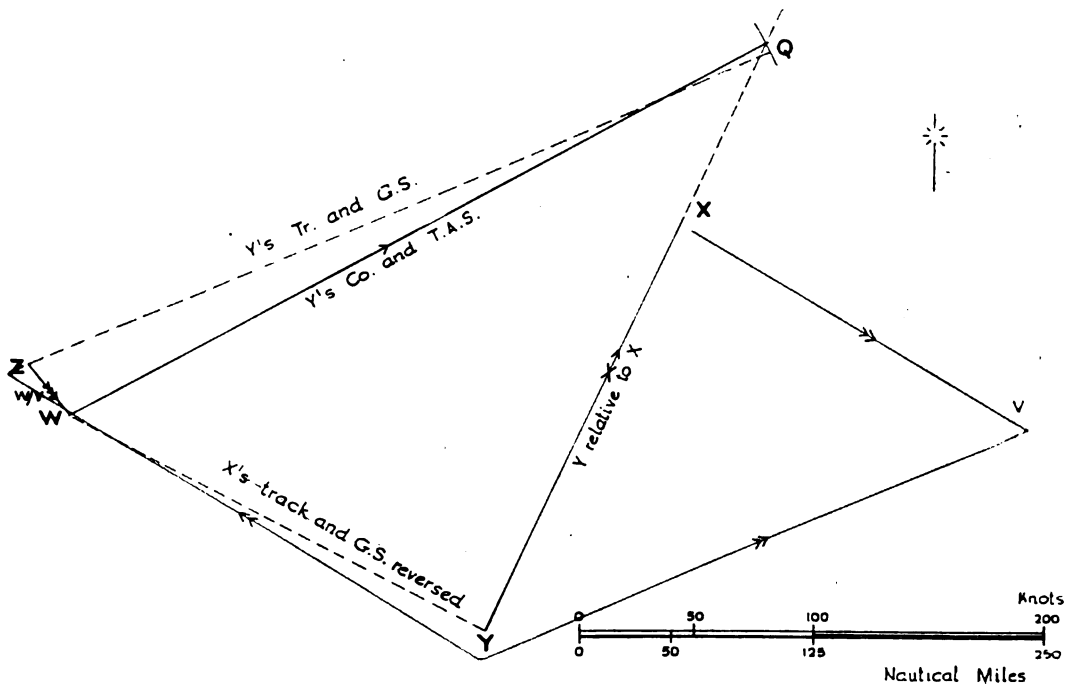


FIGURE 9. Interception, given Track and Ground Speed.

Solution :—

30. The Course and True Airspeed of the bomber can be deduced from the familiar triangle of velocities, and the problem then becomes the same as the previous example. However, this preliminary construction is usually plotted on the main velocity diagram as illustrated in Figure 9, as follows :

X and Y represent the geographic position of bomber and fighter aircraft respectively.

From Y, the bomber's reversed Track and Ground Speed vector, YZ, is drawn.

From Z, the Wind vector ZW is laid off down-wind.

Then YW is the bomber's reversed Course and True Airspeed vector. (It is not necessary to draw this line.)

With centre W and radius the fighter's True Airspeed to scale, strike an arc at Q on YX (produced if necessary).

Then WQ is the Course to intercept, 061° T.....(i).

ZQ is the Track of the fighter. If a line is drawn through Y, parallel to ZQ and cutting the bomber's Track, drawn from X, at V, then V is the geographic point of interception.....(ii).

The speed of closing is YQ, 283 k. Since the distance to close is 250 n.m., the time to intercept is (250 n.m. at 283 k =) 53 minutes.....(iii).

The E.T.I. may be checked by measuring XV and YV, the Track distances covered by bomber and fighter respectively, and dividing by their respective Ground Speeds. Thus 205 n.m. at 232 equals 308 n.m. at 347 k, namely 53 minutes.

Interception of Surface Craft by Aircraft

31. This problem is identical with that of intercepting an aircraft whose position, Track and Ground Speed are known. The Course and Speed of the ship are treated as if they were Track and Ground Speed of an aircraft operating in a Wind Velocity that is either known or assumed. The imaginary Course and True Airspeed of the ship is deduced and the problem is solved as in the previous example.

Example :—

32. An Aircraft Carrier is reported in position LJQP 2607 at 15.00 hours on a Course of 195° T, and speed 30 k. An aircraft is ordered to leave BARNSTAPLE at 15.10 hours to intercept at a height of 1000 feet and a True Airspeed of 200 k. The Wind at 1000 feet for the area is $236^\circ/25$ k.

To find :— (i) The Course to intercept.
(ii) The geographical position of interception. (G.P.I.).
(iii) The estimated time of interception. (E.T.I.).

Solution :—

33. Suppose position LJQP 2607 is in $51^\circ 26' \text{ N}$, $05^\circ 53' \text{ W}$. Then at 15.10 hours the ship has travelled 5 n.m. along its Track.

Its position at 15.10 hours, measured from a chart, is therefore 284° BARNSTABLE 71 n.m.

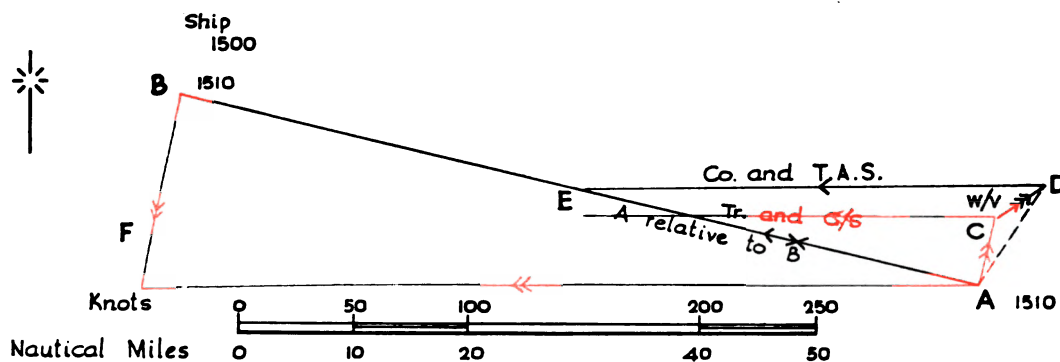


FIGURE 10. Intercepting a Surface Craft.

In Figure 10, A represents the aerodrome and B the ship at 15.10 hours. AB is therefore the distance to close and the line of constant bearing.

From A, lay off AC, the ship's reversed Course (Track) and Speed (015° , 30 k). Lay off CD, the Wind vector down-wind (056° , 25 k). Then AD represents the ship's imaginary reversed air Course and True Airspeed.

With centre D and radius the True Airspeed of the aircraft to scale, strike an arc at E on AB.

Then DE represents the Course to intercept, and CE, the Track and Ground Speed; while AE represents the speed of closing.

The Course to steer is 269° T.....(i).

Through A, draw a line parallel to CE, the aircraft's Track. This cuts the ship's Track, drawn from B, at F. Then F is the G.P.I.....(ii).

The speed of closing is 175 k, and the distance to close is 71 n.m.

Therefore it will take (71 n.m. at 175 k =) $24\frac{1}{2}$ minutes to close, and the E.T.I. will be at (15.10 hours + $24\frac{1}{2}$ minutes =) 15.34.30 hours.....(iii).

The E.T.I. should be checked by timing the aircraft and the ship along their respective Tracks to the point of interception, F, at their respective Ground Speeds.

Thus 73 n.m. at 179 k, equals $12\frac{1}{4}$ n.m. at 30 k, equals $24\frac{1}{2}$ minutes.

Intercepting an Aircraft whose Position, Track and True Airspeed are Known.

34. It may be that the observation of enemy aircraft does not reveal its Ground Speed, and yet its True Airspeed may be assumed from the operational performance of its type.

The problem is solved by first calculating the Course of the enemy aircraft from the available data. It then becomes another example of the fundamental case.

Example :—

35. An enemy aircraft is observed at 10,000 feet to be making good a Track of 053° T, and is of a type known to cruise at a True Airspeed of 220 k at that height. A fighter at A sets Course from 5,000 feet to intercept, when the enemy is at B, a position 290° A 45 n.m. The Wind for the area at the mean height (7,500 feet) is $060^\circ/35$ k. The fighter's average True Airspeed is 300 k.

To find :— (i) The Course to intercept.
(ii) The G.P.I.
(iii) The E.T.I.

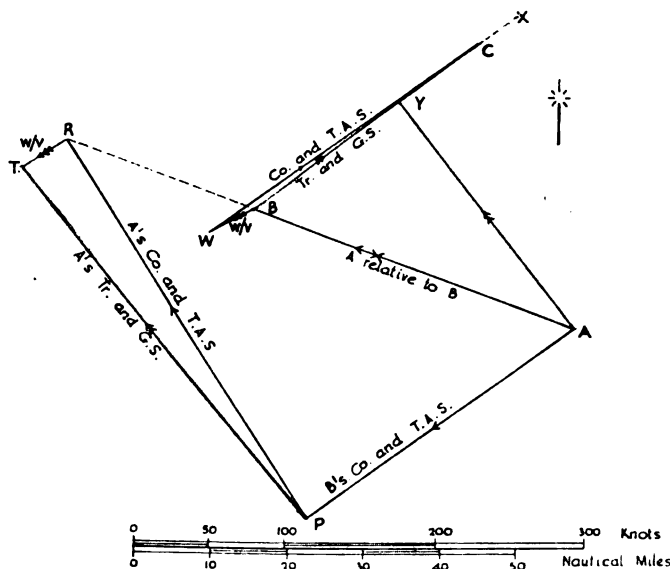


FIGURE 11. Interception, given Track and True Airspeed.

Solution :—

36. From B (see Figure 11), draw BX , the enemy's Track, and lay off BW the Wind vector downwind. With centre W and radius the enemy's True Airspeed to scale, strike an arc at C on BX .

Then WC is the enemy's deduced Course.

From A, draw AP , the enemy's reversed Course and True Airspeed.

With centre P and radius the fighter's average True Airspeed to scale, cut AB (produced if necessary) at R.

PR is the Course to intercept, 328° T.....(i).

The Track and Ground Speed of the fighter is plotted by laying off RT , the Wind vector downwind, and by joining PT .

A line drawn through A, parallel to PT , meets the enemy's Track at Y, which is the G.P.I.....(ii)

The speed of closing is AR , which measured 358 k.

The time to intercept is therefore (45 n.m. at 358 k $\Rightarrow$), $7\frac{1}{2}$ minutes.....(iii).

The E.T.I. should be checked by timing both aircraft along their respective Tracks to the point of interception, Y, at their respective Ground Speeds.

Thus AY will take (37.8 n.m. at 301 k $\Rightarrow$) $7\frac{1}{2}$ minutes.

and BY will take (23 n.m. at 186 k $\Rightarrow$) $7\frac{1}{2}$ minutes.

Intercepting an Anticipated Aircraft or Surface Craft

37. If for any reason it is desired to set Course to intercept an air or surface craft at a time *before* the latter has left its base, the problem is solved by imagining the air or surface craft to be already moving, but at some point on its projected Track that, at its Ground Speed, it will reach its base at the real moment of departure. The line of constant bearing and the distance to close is measured from the imaginary position of the craft to the position of the intercepting aircraft.

Example :—

38. At 11.20 hours an aircraft at A is ordered to set Course at 500 feet to intercept a ship due to leave port B (142 n.m., 275° T from A) at 11.30 hours on a Course (Track) of 190° T at 30 k. The mean Wind is expected to be $250^\circ/20$ k at 500 feet. The True Airspeed of the aircraft is 230 k at 500 feet.

To find :— (i) Course to intercept.
(ii) G.P.I.
(iii) E.T.I.

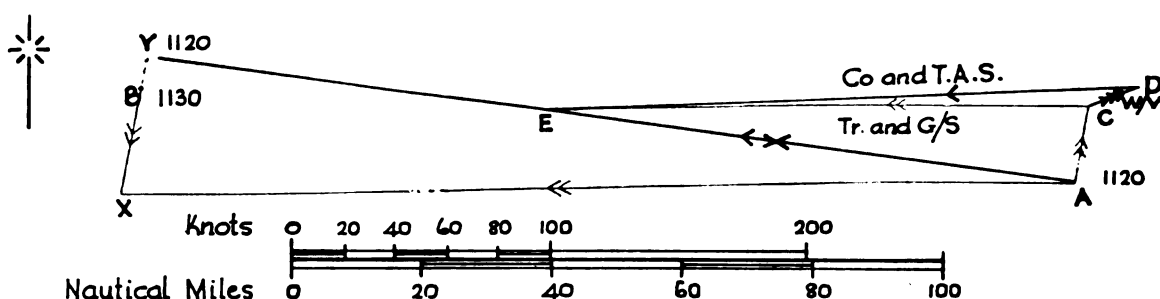


FIGURE 12. Intercepting an Anticipated Surface Craft.

Solution :—

39. In 10 minutes the ship would travel 5 n.m. in a direction of 190° T.

Draw BY, in Figure 12, equal to 5 n.m. in a direction 010° T from B. Then Y is the imaginary position of the ship at the moment Course is set to intercept it.

Join AY. This is the line of constant bearing, 278° T and the distance to close, 141 n.m.

From A, draw AC, the ship's reversed Track and Ground Speed vector. From C, lay off CD, the Wind vector down-wind.

With centre D and radius 230 k to scale, strike an arc at E on AY (produced if necessary).

Join DE, which is the Course to intercept, 268° T.....(i).

Join CE, the aircraft's Track, and through A draw a line parallel to CE cutting YB, the ship's Track produced, at X. X is the G.P.I.....(ii).

AE is the speed of closing 207 k. The time to close is therefore (141 n.m. at 207 k $\Rightarrow$) 41 minutes.

The E.T.I. is therefore (11.00 hours + 41 minutes $\Rightarrow$) 11.41 hours.....(iii).

Check :—To travel YX the ship will take (20.5 n.m. at 30 k $\Rightarrow$) 41 minutes.

To travel AX the aircraft will take (144 n.m. at 210 k $\Rightarrow$) 41 minutes.

Intercepting an Aircraft or Surface Craft which Subsequently Alters Course

40. If the craft that is being intercepted subsequently alters Course, the original Course set to intercept will no longer be of use, since the relative velocity has been changed.

The position of the intercepting aircraft and also that of the ship or aircraft being intercepted must be plotted at the moment of the latter's altering Course. The problem is solved by a completely new plot involving no new principle. It is therefore not illustrated.

$$\text{The time out, } T = \frac{R}{O} \dots \dots \dots (1).$$

$$\text{The time home, } P - T = \frac{R}{H} \dots \dots \dots (2).$$

The sum of (1) and (2) equals P, i.e.,

$$\frac{R}{O} + \frac{R}{H} = P,$$

$$\text{that is, } R(O + H) = P \times O \times H,$$

$$\text{whence } R = \frac{P \times O \times H}{(O + H)}, \text{ the radius formula} \dots \dots (3).$$

Substituting in (1) the value of R at (3),

$$T = \frac{P \times O \times H}{(O + H) O},$$

$$\text{Whence } T = \frac{P \times H}{(O + H)}, \text{ the time formula.}$$

In the example already solved graphically,

$$R = \frac{6 \times 206 \times 227}{(206 + 227)} = \frac{6 \times 206 \times 227}{433}$$

$$= 648 \text{ n.m. (by slide rule)}$$

$$\text{and } T = \frac{6 \times 227}{433} \text{ hours}$$

$$= 3 \text{ hours 9 minutes (by slide rule).}$$

48. The proportional division solved graphically in paragraph 46 can be done on the circular slide rule. By setting Ground Speed out on, say, the outer scale, against the Ground Speed back on the inner scale, two numbers are then found opposite to each other that together add up to the total time available for the patrol 360, minutes.

The numbers found in the present case are 189 and 171.

As the Ground Speed out is the lesser, the time out will be greater than the time back. Hence the time to turn will be after 189 minutes, or 3 hours 9 minutes; while the Radius of Action will be given by a speed of 206 k for this time, that is 648 n.m.

Radius of Action when only Two Tracks are Flown, Returning to a Second or Moving Base

49. An aircraft may be ordered to patrol a certain Track from a certain datum point and to return to a second datum point after a given time; or it may be ordered to leave on patrol from a moving base, such as an Aircraft Carrier, returning to a subsequent position of the same base after a given time. In each case the solution is identical; consequently the less obvious case will be considered, that of returning to a second base.

Example:—

50. An aircraft whose True Airspeed is 200 k is ordered to patrol a Track of 320° T from a position A and to return after 2 hours to position B, 100 n.m. on a bearing of 060° T and A. The wind is $015^\circ/30$ k.

- To find:—*
- (i) The Course out and Course back.
 - (ii) The time to turn (T.T.T.).
 - (iii) The geographical position of the turn.

There are three methods of solution, as follows:—

First Solution (see Figure 16).

51. Base A is imagined to move at a uniform speed so that at the end of the patrol, it will be in the position of base B. Its "Track" is therefore along line AB and its "Ground Speed" is 50 n.m.

Lay off the Wind, AW, down-wind from A. With centre W and radius the aircraft's True Airspeed, strike an arc at C on the aircraft's patrol Track AX.

The Course to steer on the outward journey is then given by WC, 327° T.....(i).

While AC represents diagrammatically the distance the aircraft will travel in one hour, AD represents diagrammatically the distance the base A is imagined to have travelled in the same time.

Therefore CD is the line of constant bearing between the aircraft and the "moving" base, and is also the speed of opening, to the chosen scale.

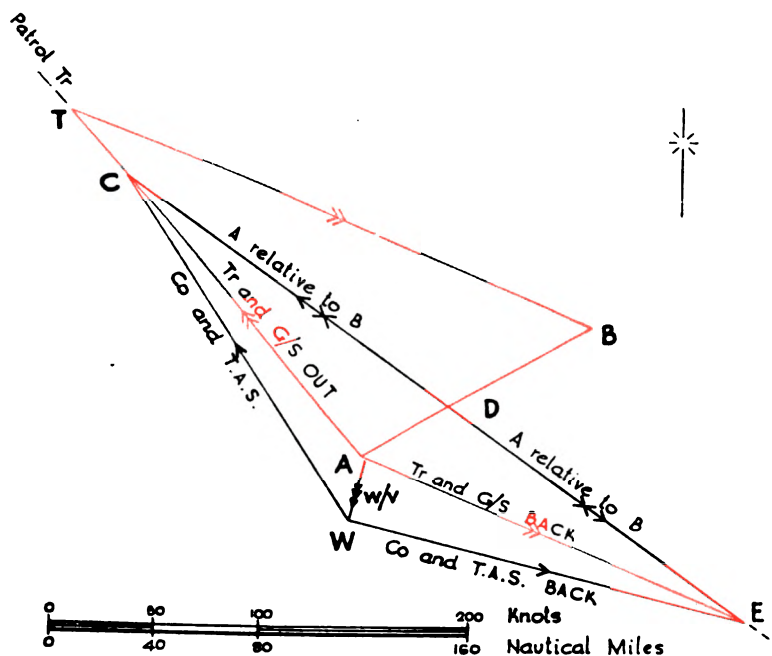


FIGURE 16. Radius of Action. Two Tracks, Second Base.

In order to return to the "moving" base, the problem is simply one of interception.

Thus with centre W, and radius the aircraft's True Airspeed to scale, strike an arc at E on the line of constant bearing CD (produced).

Then WE, 104° T, will be the Course to return to the moving base at any time.....(i).

AE is the aircraft's Track back.

Since the aircraft is to return to B, and will be on a Track parallel to AE, the turning point is determined as follows:—

Through B, draw a line parallel to AE, and cutting AX at T.....(iii).

Then AT is the Track and radius of action out from A, 171 n.m.; and TB is the Track and distance back to B.

The time to turn is given by distance AT at the Ground Speed out, that is 171 n.m. at 180 k, or 57 minutes.....(ii).

52. If the two Tracks, out and back, cut at very acute angle, some doubt will arise concerning their actual point of intersection, and consequently the Time to Turn will be in doubt. In this event it is best to calculate the time to turn from the *Out and Home* formula, expounded in paragraph 47.

$$T = \frac{P \times H}{O + H}$$

The speed of opening is given in Figure 16 by CD, 195 k; while the speed of closing is given by DE, 175 k.

$$\text{Thus } T = \frac{2 \times 175}{195 + 175} \text{ hours,} = \frac{2 \times 175}{370} \text{ hours.} \\ = 57 \text{ minutes.}$$

The distance out can then be calculated by multiplying the Ground Speed out by the Time, T, that is (180 k for 57 minutes =) 171 n.m.

53. A check should always be made, when time permits, by calculating the time to return to base B; this, together with the time T, should comprise the total time of patrol, P.

In the above case, the distance TB equals 212 n.m., while the Ground Speed back is 201 k. The return journey will therefore take 1 hour 3 minutes. Thus the total time will be 57 minutes + 1 hour 3 minutes, or 2 hours.

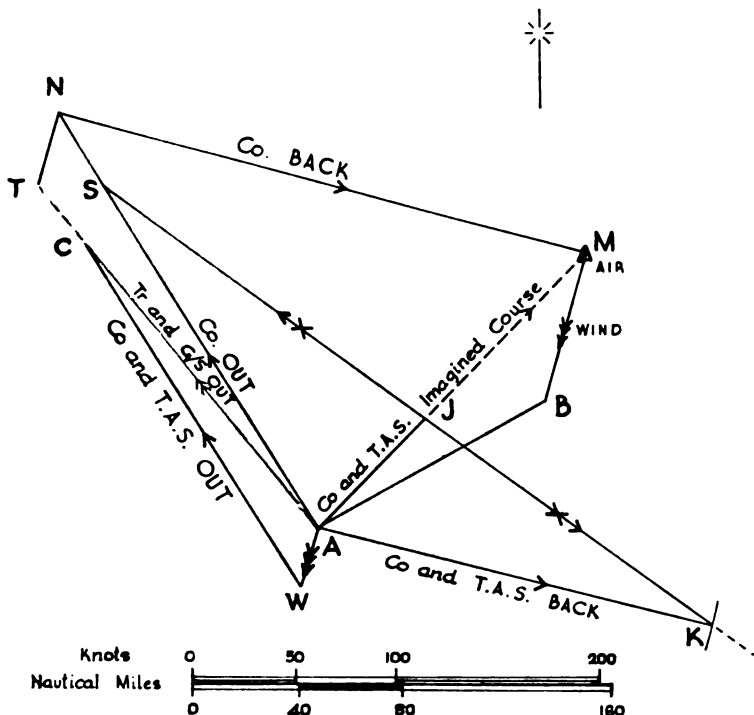


FIGURE 17. Radius of Action. Two Tracks, Second Base.

Second Solution (see Figure 17).

54. An imaginary aircraft leaving A and arriving at B at the same time as the aircraft under consideration, will fly a Course and air distance represented by AM, where M is the common air position 2 hours up-wind from B.

Since AM measures 150 n.m. in a direction of 044° T, the imaginary aircraft has a True Airspeed of $(150 \text{ k} \div 2 =) 75 \text{ k}$ and a Course of 044° T.

The constant bearing diagram can therefore be constructed to scale.

AS is the patrol aircraft's Course out, 327° T, and True Airspeed, 200 k; AJ is the imaginary aircraft's Course and True Airspeed; and SJ is the line of constant bearing.

With centre A and radius AS, strike an arc at K on SJ produced.

Then AK is the Course, 104° T, to close on the imaginary aircraft, i.e., back to base B.....(i).

Through M, draw a line parallel to AK, meeting AS produced at N, which is the air position of turning. A line drawn through N, down-wind, meeting the Track at T, gives the geographical point of turning.....(iii).

SJ is the speed of opening, and

JK is the speed of closing.

The Time to Turn may be calculated from the formula—

$$\frac{P \times H}{O + H} = T,$$

$$\text{that is, } \frac{2 \times 175}{195 + 175} = 57 \text{ minutes.....(ii).}$$

Check as before.

Third Solution (see Figure 18).

55. If the aircraft is to return to position B in two hours, it will then have an air position *up-wind* from B a distance equal to the Wind Effect for that time.

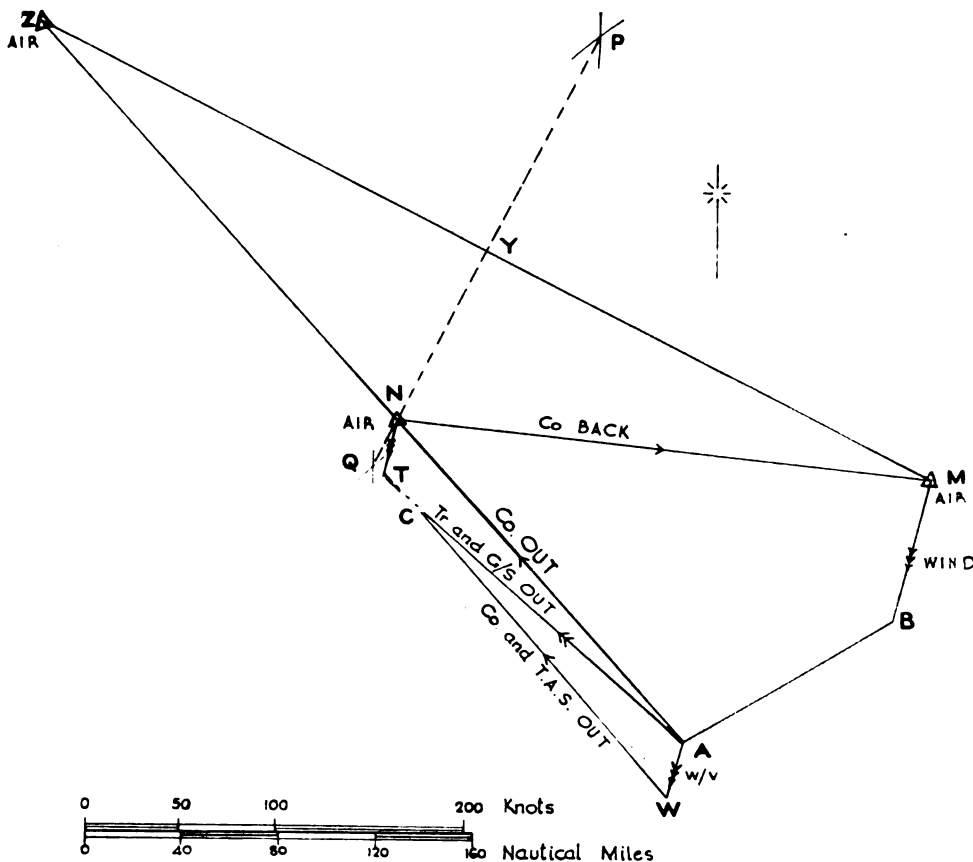


FIGURE 18. Radius of Action, Two Tracks, Second Base.

Therefore on the map or chart draw BM equal to 60 n.m. in a direction 015° T (up-wind).

As before, determine the Course to steer, 327° T, to make good the Track out, 320° T(i).

From A draw AZ, the total air distance flown on the Course out, as if the aircraft did not return to base B. This will be 400 n.m. in a direction 327° T.

Join ZM.

With centres Z and M and radius any convenient length greater than half ZM, draw arcs on either side of ZM, cutting each other at P and Q.

Join P and Q, bisecting ZM at Y, and cutting AZ at N.

Then NM is the Course back, 104° T.....(i).

Since NY bisects ZM at right-angles, NZ equals NM, and the total air distance ANM equals ANZ. $\therefore$ N is the air position of turning.

The ground position of the aircraft may be determined at any time by applying the Wind Effect to the appropriate air position. T is therefore the geographical position of the turn.....(ii).

The time to turn is determined by dividing air distance AN, 190 n.m., by the True Airspeed, 200 k. that is 57 minutes.....(iii). This should be checked as already described.

Radius of Action when More than Two Tracks are Flown, Returning to the Same or a Second Base

56. If an aircraft operating from a certain base is ordered to make good a succession of Tracks, finally remaining on one Track as long as possible before returning to the same or a second base, the problem is treated as one of a radius of action to a second base, starting from the commencement of the last Track. Any of the methods described in paragraphs 49 to 55 may be used. Only one method is illustrated below.

Example :—

57. An aircraft leaves position A at 05.00 hours, flying at a True Airspeed of 250 k, and makes good the following Tracks and distances. The last Track must be patrolled as far as possible before returning to A by 06.00 hours. The Wind is $110^\circ/30$ k.

Track (T)	Distance
280°	80 n.m.
020°	20 n.m.
080°	Unknown

To find :— (i) The radius of action along the last Track, 080° T.
(ii) The Course to return to position A.
(iii) The Time to Turn.

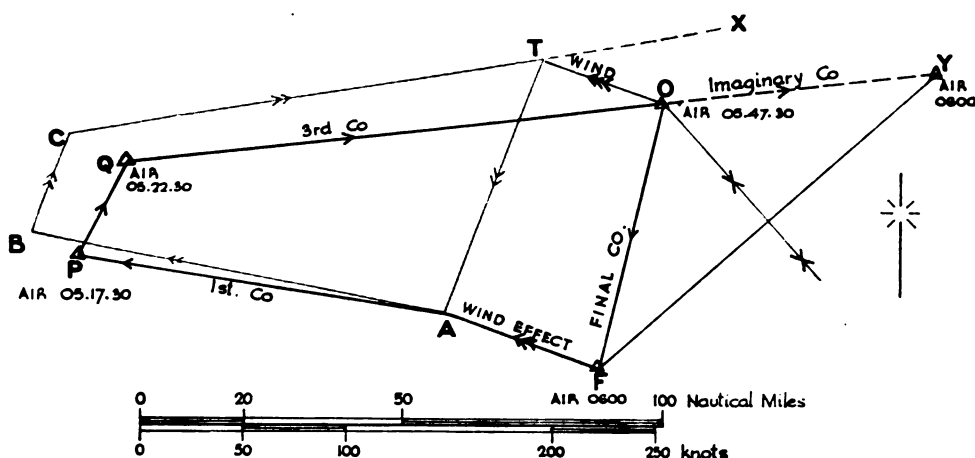


FIGURE 19. Radius of Action, More than Two Tracks.

Solution :—

58. Figure 19 shows the first two Tracks of the aircraft, namely AB and BC.

The problem is to determine a point on the third Track, CX, where the aircraft must turn towards A. The time already spent on completing the first Tracks amounts to $22\frac{1}{2}$ minutes. There still remains $37\frac{1}{2}$ minutes for the patrol. The air plot AP, PQ is shown up to 05.22.30 hours.

Plot the air position of the aircraft at the time when it arrives over A again. That is to say, the Wind Effect in 1 hour will be 30 n.m. from a direction of 110° T. AF is the Wind Effect plotted up-wind from A. Hence F is the air position at 06.00 hours.

Through Q, draw QY equal to the total air distance flown at 250 k in the remaining time, $37\frac{1}{2}$ minutes, namely 156 n.m.

Join FY, and bisect it at right-angles with a line cutting QY at O.

Through O, draw a line parallel to the Wind Direction, cutting CX at T.

Then OT is the radius of action on the last Track, a distance of 91 n.m.....(i).

OF is the Course to return to A, 193° T.....(ii).

The time to fly QO at the True Airspeed, is (104 n.m. at 250 k $\Rightarrow$) 25 minutes.

The time to turn is (05.22.30 + 25 minutes $\Rightarrow$) 05.47.30 hours.....(iii).

Check : OF represents the air distance back. This will take $12\frac{1}{2}$ minutes.

$25 + 12\frac{1}{2}$ minutes = $37\frac{1}{2}$ minutes the total time available.

Return After Shadowing or from Convoy Patrol

59. If an aircraft is engaged on shadowing duties or convoy patrol, it is necessary for it to remain on those duties as long as possible before being relieved. The problem of *when* and *where* it must be relieved is best treated as one of radius of action to a second base. The Track and Ground Speed of the aircraft while engaged on its tactical duties are taken to be those of the ship or convoy in whose vicinity the aircraft remains.

Example :—

60. An aircraft based at B is engaged on shadowing an enemy surface craft situated 200 n.m. on a bearing of 280° T from B at 10.00 hours. The enemy's Track and Ground Speed are observed to be 055° T, 20 k. The aircraft's True Airspeed is 260 k. The Wind is $135^\circ/30$ k. The aircraft has endurance until 13.00 hours.

To find :— (i) What its Course to base will be.
(ii) At what point the aircraft will expect to be relieved.
(iii) How long the enemy can be shadowed by the aircraft.

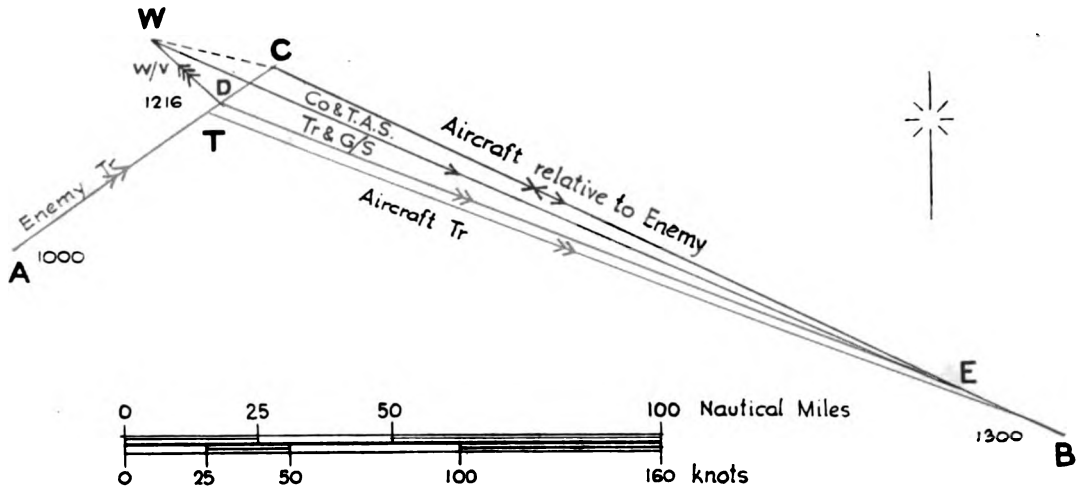


FIGURE 20. Return after Shadowing.

Solution :—

61. Figure 20 represents the relative positions of the base B and the enemy at 10.00 hours.

Plot the enemy's position at 13.00 hours ; that is, draw AC in a direction of 055° T, 60 n.m. in length.

Then when the aircraft has returned to B, the enemy will be at C. Consequently BC is the line of constant bearing and the distance to open from the enemy after the aircraft ceases to shadow it.

To complete the constant bearing diagram on CB, lay off CD along CA to represent, to a convenient scale, the enemy's reversed Track and Ground Speed. From D lay off the Wind vector DW down-wind. With centre W and radius the aircraft's True Airspeed, strike an arc at E on CB.

Then WE is the Course to steer for the base, 114° T.....(i).

DE is the Track and Ground Speed to scale.

(WC is the imaginary Course and True Airspeed of the enemy.)

Finally, CE is the speed of opening from the enemy, 222 k.

Through B, draw a line parallel to DE, meeting AC at T. Then T is the turning point on the enemy's Track.....(ii).

The time to be relieved is given by distance AT at the enemy's Ground Speed, i.e. $(45\frac{1}{2}$ n.m. at 20 k $\Rightarrow$ 2 hours 16 minutes, or 12.16 hours.....(iii).

This may be checked by timing the aircraft on its Track to base. T.B. is a distance of 172 n.m. and the Ground Speed is 232 k. Hence the time will be 44 minutes : thus the aircraft will arrive at B at 13.00 hours.

62. The most satisfactory method of timing the turn is by calculating the duration of the run home from the distance to open from the enemy, CB, at the speed of opening, CE (to scale). This time will be (164 n.m. at 222 k $\Rightarrow$ 44 minutes).

Therefore the time spent in shadowing will be (3 hours — 44 minutes $\Rightarrow$ 2 hours 16 minutes).

The turning point is then calculated by multiplying the time spent in shadowing by the Ground Speed of the enemy, i.e. (2 hours 16 minutes at 20 k $\Rightarrow$ $45\frac{1}{2}$ n.m., laid off along the enemy's Track from A.

63. The enemy may not make good a constant Track, particularly if shadowing is suspected. In this case the enemy's Tracks and Ground Speeds should be carefully observed and plotted and a mean Track and Ground Speed deduced, from which the shadowing problem may be solved.

If the Tracks do not indicate any particular mean line of advance, but appear to be haphazard, the problem must be worked out for each separate Track and Speed of the enemy.

Accompanying a Convoy on a Track TO or FROM the Aircraft's Base

64. If the Track of the convoy which an aircraft is accompanying is directly to or from the aircraft's base, the problem is solved by the same method as described in paragraph 62.

Example :—

65. A flying boat cruising at 200 k is assigned for anti-submarine patrol with a convoy that is proceeding at 10 k and heading for the aircraft's base. At 12.00 hours the convoy is 250 n.m. away from this base on a bearing of 260° T. The Wind for the area is $350^\circ/30$ k. The safe endurance of the flying boat expires at 18.00 hours.

To find :— (i) When the flying boat must be relieved.
(ii) Where the convoy will be at that time.
(iii) The return Course of the flying boat.

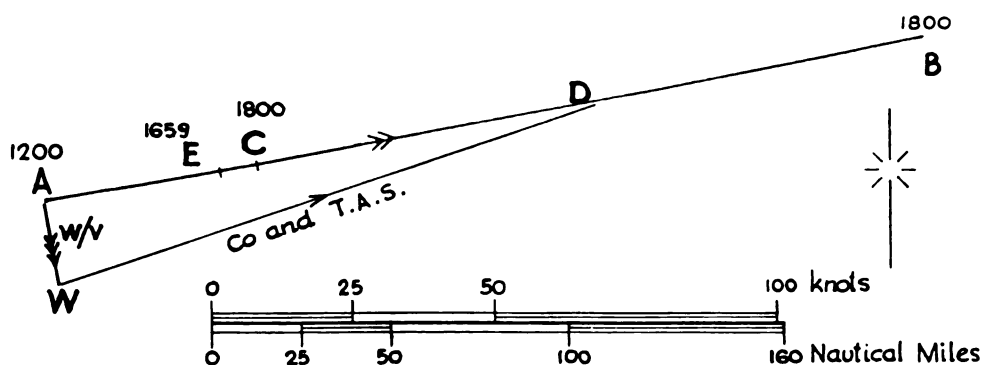


FIGURE 21. Accompanying a Convoy on a Track to the Aircraft's Base.

Solution :—

66. Figure 21 shows the relative position of the convoy and base at 12.00 hours, A and B respectively.

Plot the position of the convoy at 18.00 hours, C. Then CB is the distance that the aircraft must have opened from the convoy by 18.00 hours, 190 n.m.

The speed of opening will be the Ground Speed of the aircraft after it leaves the convoy *less* the Ground Speed of the convoy.

Lay off AW, the Wind vector, down-wind from A. With centre W and radius the aircraft's True Airspeed, strike an arc on AB at D.

Then AD represents the Ground Speed of the aircraft, which is found to be 197 k.

The speed of opening is therefore $(197\text{ k} - 10\text{ k}) = 187\text{ k}$.

The time spent on the return flight to B will be $(190\text{ n.m. at } 187\text{ k}) = 61\text{ minutes}$.

Hence the convoy is left at 18.00 hours minus 61 minutes; in other words, the flying boat must be relieved by 16.59 hours.....(i).

The convoy's position at 16.59 hours will be E, 50 n.m. from A.....(ii).

The return Course of the aircraft will be 071° T (the direction of WD).....(iii).

(Note.—If the convoy is departing from the aircraft's base, the speed of opening, on the return to base, will be the Ground Speed of the aircraft *plus* the Ground Speed of the convoy.)

Radius of Action while Keeping Station

67. An aircraft keeping station on a convoy moves along the mean line of advance of the convoy at the speed of the convoy, while at any particular time it may be some distance from the actual station. (See paragraph 19.)

The decision regarding the actual time to turn for a shore base may be made roughly by using the mean line and speed of advance. It may also be deduced accurately by plotting the position of a real or imaginary aircraft that has remained on patrol up to the moment when the shore base must be reached, thus giving a line of constant bearing between the aircraft concerned and the real or imaginary aircraft that continues the patrol. The Track to the shore base is thereby determined, and the actual point of the patrol at which Course must be set for base is found by plotting.

Example :—

68. An aircraft, whose True Airspeed is 240 k, is keeping station 10 miles on either side of a point 20 n.m. bearing 315° T from a convoy, by making good alternate Tracks of 319° T and 131° T. The convoy is moving at 15 k in a direction of 040° T. The Wind Velocity is $350^\circ/30$ k.

At 09.00 hours the aircraft is at A, and has $2\frac{1}{2}$ hours' endurance left. Its shore base, B, is 200 n.m. away on a bearing of 090° T.

To find :— (i) The Course to return to the base.
(ii) The geographical position of turning.
(iii) The time to turn for the base.

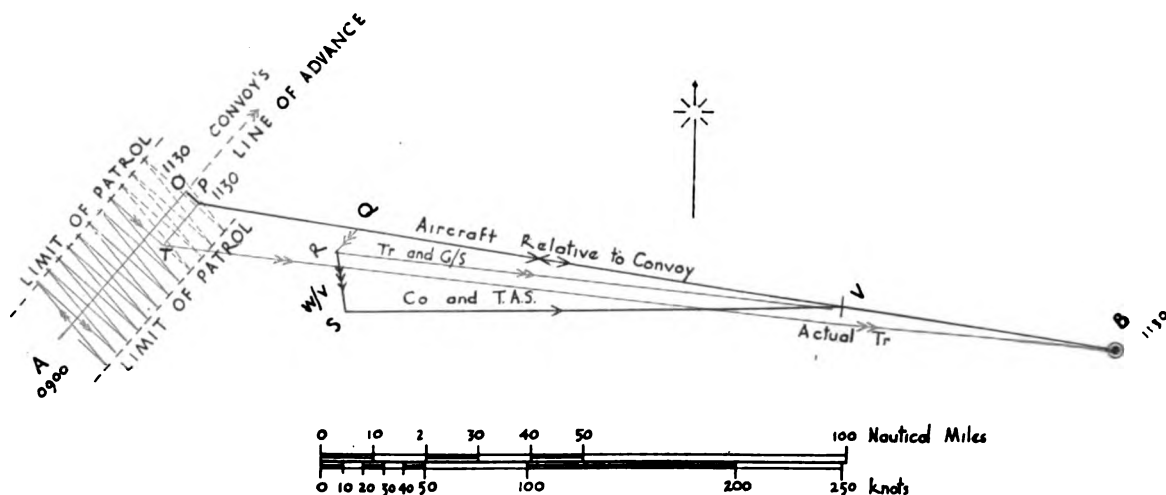


FIGURE 22. Radius of Action while Keeping Station.

Solution :—

69. A in Figure 22 is the position of the aircraft at 09.00 hours, and B represents the shore base.

Draw AO to represent the progress of the aircraft in $2\frac{1}{2}$ hours, i.e. ($2\frac{1}{2}$ hours at 15 k $\Rightarrow$ $37\frac{1}{2}$ n.m.) in a direction of 040° T.

Step along AO the patrol Tracks of the aircraft keeping station up to the vicinity of O. Erect a perpendicular at O, to cut the Track of the aircraft at P.

Then P is the imaginary position of the patrolling aircraft at 11.30 hours.

Join PB, the line of constant bearing, and construct the familiar constant bearing diagram, QRSV.

SV represents the Course to the base, 089° T.....(i).

RV represents the Track and G/S to the base, 096° T, 246 k.

Through B, draw a line parallel to RV, cutting a line through P, parallel to the convoy's Track, at T.

Then T is the furthest point that it is possible to patrol before turning for B.....(ii).

The turn should be made at such a time that the convoy will travel a distance TP (11 n.m.) while the aircraft returns from T to B (181 n.m.). Both of these times will be found to equal 44 minutes. The aircraft must therefore turn at (11.30 hours — 44 minutes $\Rightarrow$ 10.46 hours.....(iii).

T may not be a point on one of the patrol Tracks as shown, but this will have little appreciable effect on the plotting. The turn should still be made at 10.46 hours, and a Course of 089° T set for B.

Critical Point

70. The critical point in flight is that position between two bases from which it is equally quick to fly to either base.

When operating over the sea, or over undeveloped territory, there may be no possibility of making a landing at any intermediate point on the journey. Circumstances may arise, as, for example, the failure of an engine, which make it desirable to alight as soon as possible. If the critical point has not been reached, then it will be quicker to return to the point of departure rather than continue to the destination. If the critical point has been passed, it will be quicker to continue to the destination.

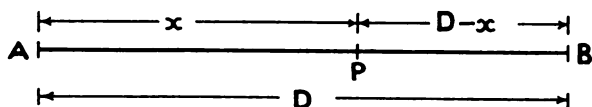


FIGURE 24. Critical Point by Formula.

The position of P is such that the time to go from P to B at the reduced Ground Speed out must equal the time to go from P to A at the reduced Ground Speed back (see Figure 24). That is:—

$$\frac{D-x}{O} = \frac{x}{H}$$

equating, $DH - xH = xO$,
 that is, $x(O + H) = D \times H$,
 Whence, $x = \frac{D \times H}{O + H}$, the distance formula ;

Thus $\frac{D \times H}{G(O + H)}$ is the time formula for reaching the critical point.

Substituting the values of D, O, G and H, already plotted or calculated from the data given, the critical point is situated from A a distance of $\frac{300 \times 159}{(135+159)} \text{ n.m.} = \frac{300 \times 159}{294} \text{ n.m.} = 162 \text{ n.m.}$

The time to arrive at the critical point is the time to fly 162 n.m. at an actual Ground Speed of 236 k, i.e., 41½ minutes.

Critical Point between a Fixed and a Moving Base

75. An aircraft flying from a fixed to a moving base, or from a moving base to a fixed base may, in emergency, have to proceed to whichever is the nearer in Time.

The problem of determining the critical point on such a flight is resolved by finding a point on the original Track from which it is equally quick at the reduced True Airspeed to proceed to the destination, as to return to the base of departure. In both bases the Track of the aircraft to the fixed base will be unaffected by the reduction of True Airspeed ; but the Track to the moving base will be different, since the relative velocity between aircraft and moving base is changed when the True Airspeed is reduced.

The alternative contingencies are illustrated in the following examples.

Example:—

76. A Navigator in an Aircraft, whose cruising True Airspeed is 260 k, sets Course at 12.00 hours from an aerodrome at A for an Aircraft Carrier, at that time 275° T from A, distant 240 n.m. The

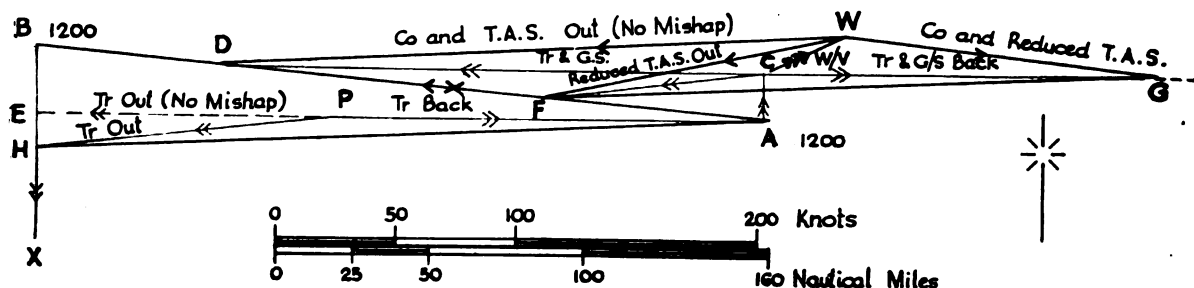


FIGURE 25. Critical Point between a Fixed and a Moving Base.

Carrier is proceeding at 20 k in a direction of 180° T. The Wind is 245°/35 k. At 12.30 hours the Aircraft is damaged by shell fire, the True Airspeed is reduced to 130 k, and height cannot be maintained. To which base should the Aircraft proceed ?

Solution :—

77. A and B in Figure 25 represent the relative positions at 12.00 hours of Aircraft and Carrier. AB is therefore the line of constant bearing and distance the Aircraft must close.

By constructing the familiar constant bearing diagram, ACWD, the Course and Track to intercept the Carrier are plotted, using the cruising True Airspeed (WD to scale).

Through A, draw a line parallel to CD, the Track out, meeting the Carrier's Track at E, the G.P.I. at the cruising True Airspeed.

After the True Airspeed is reduced, the line of constant bearing between the Aircraft and the Carrier remains as before (BA). Therefore with centre W, and radius 130 k to scale, strike an arc on AB at F.

Then AF is the new speed of closing to the Carrier; and CF is the new Track and Ground Speed to intercept, whatever the position of the Aircraft when the True Airspeed is reduced.

Since the Aircraft would return to A down the Track already made good from A, strike an arc on DC, produced, at G, with centre W and radius the reduced True Airspeed.

Join GF, and through A draw a line parallel to GF, meeting BX at H. Through H, draw a line parallel to CF, the new Track to the Carrier, meeting AE at P.

Then P is the critical point, a distance of 142 n.m. from A. The original Ground Speed to intercept the Carrier was CD, 227 k. Therefore the critical point is reached in 38 minutes, or at 12.38 hours.

Therefore at 12.30 hours the Aircraft should return to its base, A.

Example :—

78. An Aircraft whose cruising True Airspeed is 260 k leaves an Aircraft Carrier, A, at 12.00 hours for a shore base B, bearing 265° T and 180 n.m. distant. The Carrier is travelling at 20 k, on a Track of 000° T. The Wind is $290^\circ/30$ k.

At 12.25 hours the Aircraft sustains damage that reduces its True Airspeed to 130 k, and causes a steady loss of height. To which base should the Aircraft proceed?

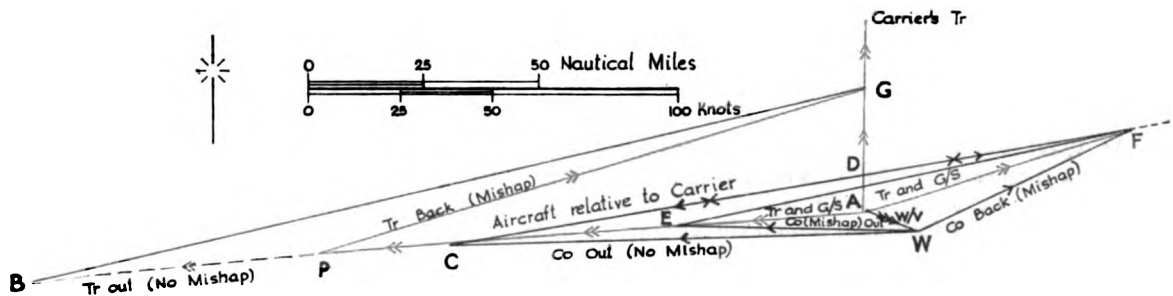


FIGURE 26. Critical Point between a Moving and a Fixed Base.

Solution (See Figure 26) :—

79. The Course to steer for B at the cruising True Airspeed is obtained by the familiar triangle of velocities, AWC. AC is therefore the original Ground Speed towards B.

Meanwhile the Carrier has proceeded 20 n.m. along its Track from A to D (constructional scale). Therefore the line of constant bearing (as long as the cruising True Airspeed is maintained outwards) is given by CD.

When the True Airspeed is reduced, the Track to B remains unchanged, but the Ground Speed becomes AE, and the new Course for B becomes WE.

With centre W and radius the reduced True Airspeed to scale, strike an arc at F on CD produced.

WF is then the Course to return to the Carrier at any time at the reduced True Airspeed; and AF is the Track and Ground Speed.

Join EF. Through B draw a line parallel to EF meeting the Carrier's Track at G.

Through G draw a Track parallel to AF, cutting AB at P, the critical point.

AP measures 117 n.m., and the Aircraft covers this distance with cruising True Airspeed at a Ground Speed of 232 k (AC to scale). It arrives at P in 30 minutes, namely, at 12.30 hours.

Therefore at 12.25 hours the Aircraft should proceed back to the Carrier.

80. In practice the decision to go on or return may be made from an intelligent estimation of the situation. However, much as the following problems are unlikely to be met by the Navigator in the air, they afford a useful means of sharpening his navigational ability and plotting-sense, and are therefore of value in his training.

Critical Point between Two Moving Bases

81. An aircraft flying between two moving bases has *two* relative velocities.

Suppose an aircraft leaves a moving base at A and intercepts a second moving base at B₃.

At times Zero, T₁, T₂, T₃, the following positions are plotted (see Figure 27) :—

Base A	...	...	A,	A ₁ ,	A ₂ ,	A ₃ .
Base B	...	...	B,	B ₁ ,	B ₂ ,	B ₃ .
Aircraft	...	...	A,	C,	D,	B ₃ .

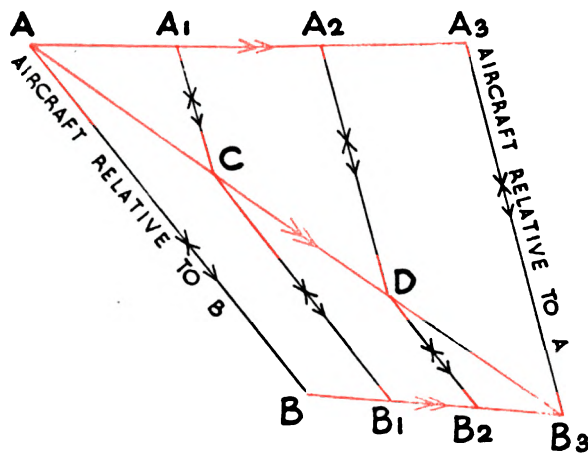


FIGURE 27. An Aircraft Flying between Two Moving Bases.

It can be seen that the aircraft maintains a constant speed of opening and a constant bearing with base A, and a constant speed of closing and a constant bearing with base B.

At any time, therefore, the Course to set for either base may be plotted, and the Tracks and Ground Speeds determined.

82. To find the critical point, a position must be found on the original Track of interception from which the lengths of the new Tracks to intercept either base are directly proportional to the respective Ground Speeds. If these conditions are obtained, the time to either base will be identical.

The plotting involved is probably the most complex construction known to Navigation.

Example :—

83. An aircraft cruising at a True Airspeed of 160 k is in company with an Aircraft Carrier travelling at 30 k in a direction of 070° T. The Wind is 060°/20 k.

At 12.00 hours the Air Navigator sets Course to make contact with a Speed Boat travelling at 40 k, in a direction of 270° T, whose position at 12.00 is 045° T, distant 200 n.m. from the Carrier. At 13.00 hours the aircraft sustains damage which reduces the True Airspeed to 80 k and necessitates an early landing. To which base should the aircraft be flown ?

Solution :—

84. In Figure 28 (b) X and Y are the respective positions of the Carrier and the Speed Boat.

In Figure 28 (a), AB represents the line of constant bearing between aircraft and Speed Boat which it is desired to intercept. By constructing the familiar constant bearing diagram, ARWC, the Course to intercept, WC, and Track and Ground Speed, RC, are plotted.

As in Figure 28 (b), draw a line through X parallel to the Track out, RC, meeting the Speed Boat's Track at I. The question is: At what point on this Track, XI, will it be as quick for the aircraft to fly at the reduced True Airspeed to intercept either the Speed Boat or the Aircraft Carrier ?

If the aircraft is considered to depart from the point R in Figure 28 (a) at 12.00 hours, in one hour it will have reached C, and the Carrier will have reached D. Therefore CD, produced, is the line of constant bearing between the aircraft and the Carrier after 12.00 hours. If the aircraft is to intercept the Carrier at any time, it is along this line of constant bearing that the aircraft will close on the Carrier.

Thus, by constructing a second constant bearing diagram, DRWE, using the reduced True Airspeed, WE becomes the Course, and RE the Track and Ground Speed to intercept the Carrier at any time at the reduced True Airspeed.

Similarly, the new Course and new Track and Ground Speed to intercept the Speed Boat at the reduced True Airspeed are obtained by striking an arc on AB at F, with centre W and radius the reduced True Airspeed.

Hence with the reduced True Airspeed, RF is the Track and Ground Speed to the Speed Boat, and RE, the Track and Ground Speed to the Carrier. Join EF (blue).

In Figure 28 (b), two lines are drawn parallel to EF, cutting the two ships tracks at E₁, F₁, and E₂, F₂, as shown in blue.

Through F₁ and F₂, draw lines parallel to RF.

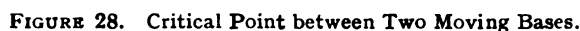
Through E₁ and E₂, draw lines parallel to RE, cutting the lines just drawn at R₁ and R₂.

The Ground Speed along XI is RC, 140 k. Therefore the critical point is reached in 45 minutes, i.e. at 12.45 hours. Therefore at 13.00 hours the aircraft should set Course 028° T for the Speed Boat.

85. Through P, draw lines parallel to RE and RF, cutting the two ships' Tracks at E₂ and F₂.

That is to say, the distances from P to intercept either the Carrier or the Speed Boat are proportional to their respective Ground Speeds, and the time spent on either will be identical.

Alternatively, PF₃ = 53 n.m. The G/S would be 64 k (RF). Thus it would take 50 minutes to intercept the Speed Boat.



Note.—The data for this example has been specially chosen so that the constructional diagram might be as clear as possible. The introduction of more normal speeds would not alter the construction, but would add a little to the confusion.

Lines of Constant Relative Bearing on Mercator's Projection

86. The line of constant relative bearing between two moving objects on the Earth is, strictly speaking, an arc of a great circle. It follows that when any problem, involving the measurement of constant bearings, is plotted on a Mercator's map, the use of rhumb lines in place of arcs of great circles introduces some error which increases with the length of the rhumb lines employed.

Hence, while the Constant Bearing Diagrams may be correctly drawn to any *arbitrary* scale, the subsequent plotting of the actual Tracks and distances may not be wholly accurate.

In practice the distances are nearly always short enough for this consideration to be ignored.

CHAPTER XI

GROUND ORGANISATION.

*"There was one who was famed for the number of things
He forgot when he entered the ship :"*

—THE HUNTING OF THE SNARK.

General

1. Air Navigators in the Royal Air Force must keep well-informed on all useful developments in technique and equipment. The following notes give a general outline of the ground organisation which ensures that the needs of the Air Navigator are fully covered. It should, however, be realised that the Air Navigator is expected to take an active part in acquiring information himself, and he should always be willing to pass on to others the benefit of his own experience, whether or not this has been to his credit.

The Navigational Staff

2. There is a continuous line of contact between the Unit in which the Air Navigator finds himself, and the Air Ministry. This contact enables navigational policy to be implemented, provides for continual supervision of the standard of practical work attained by the Unit, and helps to maintain efficiency. The main links in the chain of communication are as follows :—

(i) The Squadron Navigation Officer

The duties of the Squadron Navigation Officer are detailed in K.R. and A.C.I., paragraph 760. They may be summarised under three headings :

(a) *Instructional.* These duties require force of character and keenness, coupled with the confidence of the Squadron. The Squadron Navigation Officer is able to give valuable advice to individuals at a time when their difficulties are most vividly recalled—immediately after each flight. Discussion with returning air crews, in conjunction with the Intelligence Officer's interrogation, goes far to consolidate the training of the Squadron as a whole.

(b) *Technical.* The Squadron Navigation Officer must see that all navigational equipment is properly cared for, and in good order. A close liaison with both Engineer and Equipment Officers is most valuable. He must also know what instruments, maps, and publications are available. A fully-equipped Navigation Office should be provided where all information affecting the Squadron's Navigators can be readily found. A close liaison with the Meteorological Officer, the Intelligence Officer, the Signals Officer and the Flying Control Officer is necessary to keep the information up to date.

(c) *Administrative.* The Squadron Navigation Officer may be called upon to report on any outstanding navigational matter affecting his Squadron.

(ii) The Station Navigation Officer

At many stations he must perform those duties detailed above for the Squadron Navigation Officer. Where he is assisted by Squadron Navigation Officers, he should relieve them of as much Administrative work as possible and ensure that they are carrying out their duties thoroughly. He should be able to take a more general view of the Navigation of the squadrons on his station, and should act as navigational adviser to the Station Commander, as, for example, on the assessment of an individual's navigational ability.

(iii) Group and Command Navigation Officers

These officers act in an advisory capacity on the Headquarters Staff.

They are also concerned with the navigational efficiency of the units which they administer.

They, too, work in close liaison with all ancillary branches of the Service.

They maintain a record of the work of individual Air Navigators, for selection as advanced trainees.

They ensure that units are kept well-informed of navigational progress, and that all problems encountered by units are investigated without delay.

Operations Room

3. This is an essential feature of Station Headquarters, for it provides the Commanding Officer with a control centre for all matters of intelligence affecting the operation of his aircraft.

The movements of aircraft are reported from the Signals Office, and from Flying Control, and are recorded in a systematic way in the Operations Room, as well as being passed on to Group Headquarters Operations Room. By this means it is possible to keep a watchful eye on a large number of aircraft operating at the same time; and, by anticipating troubles that may occur, suitable arrangements can usually be made to assist aircraft in difficulties without undue delay.

The Signals Officer

4. The Signals Officer is an important member of the ground organisation behind the Air Navigator, who requires up-to-the-minute information concerning the location, frequencies and call signs of D/F stations and beacons operative during an intended flight.

In addition, the Signals Officer will ensure that all signals equipment is thoroughly maintained. Full use should be made of his technical knowledge by discussing with him problems encountered in flight.

Map Officer

5. The Officer detailed by the Station Commander under A.M.O. A.914/40 should keep the maps on behalf of squadrons on the Station.

He must issue maps on demand to individuals, and ensure that they are used economically. Some kind of accounting is necessary to prevent stocks running low. (See also Chapter III.)

Directorate of Military Survey (Responsibility for the Supply of Maps)

6. The Deputy Directorate of Survey is particularly charged with the responsibility for R.A.F. requirements. G.S.G.S. (A) is the section primarily concerned with the interpretation of new requirements, while G.S.G.S. (D) is responsible for the distribution of maps. All other sections of the directorate are, however, also engaged on work for the Royal Air Force.

The Meteorological Service

7. A meteorological office is established at all operational aerodromes and at all Command and Group Headquarters where operations are controlled.

There are four categories of meteorological office, as follows :—

Type 1, attached to Group Headquarters in Bomber, Fighter and Coastal Commands and to Command Headquarters. These can provide forecasts immediately at any time.

Type 2, attached to certain Stations which require an independent forecast service, but not on a whole-time basis. When the forecasting officers are not on duty, meteorological staff of lower grade are available and can obtain any information required from the nearest Type 1 office.

Type 3, are attached to Bomber and some Coastal Command Stations. They are not independent forecasting offices, and obtain forecasts from the *Type 1* at Group Headquarters. The staff are competent to explain the meteorological reasons for the forecasts. An important part of their duties is to attend the briefing conference before an operation, to explain the anticipated weather to the air crews participating and to answer questions.

Type 4, attached to certain Stations where normally only short-range operations are carried out, such as at Fighter Stations. The staff obtain all forecasts from the *Type 1* office at Group Headquarters. They decode all coded reports and act generally as a link between the Station and the *Type 1* meteorological office at Group Headquarters.

At all these offices, except at some *Type 1* offices, a continuous watch is maintained on the weather.

8. A special card, Form 2330, is provided for the supply of route forecasts, and a route forecast on this form must be obtained from the meteorological office before a flight is made exceeding 100 miles. In the case of shorter flights, the C.O. of the station or the officer in charge of flying is responsible for deciding whether information is to be obtained on Form 2330 or verbally.

Space is provided in the reverse side of Form 2330 for the entry of observations made in flight. The card is handed to the meteorological office on arrival at the destination. These observations are often of very great value, especially when made over the sea or enemy territory. Arrangements are in force to enable the information so obtained to be broadcast to all other stations.

9. The request for a route forecast should be made to the meteorological office as early as possible before a flight, by the Pilot in person if possible, stating the intended route, and approximate time of departure and arrival.

It is most important that the distinction between a route forecast and a weather report should be clearly understood. A *route forecast* is a forecast of the weather for a specified route or area and period of time. A *weather report* is a statement of the observed weather at a specified place and time. It is a *route forecast* that is needed before a flight, not a weather report. Form 2330, already referred to, may contain the latest weather reports from certain places along the route. These reports do not necessarily describe the weather which will be experienced when the aircraft arrives over the place. The *forecast* will indicate what changes in the weather described in the reports are to be expected whilst the flight is in progress.

10. In addition to providing route forecasts for specified flights, the meteorological service issues local forecasts for aerodromes and warnings of the onset of gales, squalls, thunderstorms and severe frost. It is the duty of the meteorological service to keep the weather constantly under review in relation to the programme of flying. The meteorological officer must therefore be kept fully informed of the latter.

11. Personal contact between Pilot and Navigator and meteorological officer is of the highest importance and, whenever possible before a flight, a discussion should be held over the weather map with the meteorological officer.

All weather information is strictly secret in wartime.

In peace time, information is exchanged daily on a world-wide basis, and reliable weather forecasts can often be made for considerable periods ahead, applicable to large tracts of country. In war, such information is not available, and forecasts are largely a question of *inference*. It follows that any meteorological information that can be obtained during operational flights far into enemy territory is of great value to the Meteorological Service as a whole.

Flying Control

12. The primary object of a Flying Control is to render assistance to aircraft on request. A number of Flying Control Centres are located at aerodromes throughout the country, with subsidiary stations affiliated to them. At each Centre, a 24-hour watch is kept by trained Control Officers able to help aircraft that require information or instructions.

Most valuable assistance is given on questions concerning :—

- (i) Weather conditions at aerodromes, whether FIT or UNFIT (for landing).
- (ii) FIT aerodromes to which aircraft may proceed in emergency.
- (iii) Short-range H.F. D/F and homing. D/F bearings for fixing position by the Navigator.
- (iv) Controlled approach to aerodromes in bad visibility.

Captains of aircraft should know the location and wireless frequencies of these Flying Control Centres from which assistance may be required during flight.

In order to derive most benefit from the organisation, the following degrees of priority must be rigidly observed :—

<i>Degree of Priority</i>	<i>Priority Significance</i>
X	Practice Calls only.
D	Normal priority ; No undue urgency.
P	Urgent and immediate ; Aircraft in difficulties.
S.O.S.	Grave Emergency ; Aircraft in great danger.

13. Messages requesting facilities should be made in the following order :—

To :
From :
Priority :
Control :
Assistance Required :

A Flying Control Centre has at least two wireless frequencies, one the Guard wave, upon which communications are made and which may also provide D/F bearings, the second being the H.F. D/F wave. The Control should be called up on the Guard frequency first, in order to avoid undue congestion on the H.F. D/F wave, upon which other aircraft may be homing. Should the Guard wave be congested, another station should be tried. D/F bearings should not be asked for when more than 100 miles from a Centre.

When time and stress of circumstances do not permit the use of *Rekoh*,* a special code is used in messages to and from Flying Control. This is called the *Q Code* (C.D. 75, Table VIII) because each phrase is expressed by a group of three letters beginning with "Q." Air Navigators, and Captains of aircraft should be familiar with the more common phrases of this code. For example :

<i>QDM</i>	...	...	" The Magnetic Course to steer to reach me is....."
<i>QFE</i>	...	...	" The Barometric Pressure of Aerodrome level is....."
<i>QFG</i>	...	...	" You are above the aerodrome (or D/F hut)."

The use of *IMI* after any *Q* group denotes a question. For example :

QDM IMI ... " What is my Magnetic Course to steer to reach you ? "

Details of the Flying Control Organisation in War are given in A.M.C.O. A24/42.

Distress Organisation

14. In emergency, the Air Navigator can rely not only upon Flying Control but also upon certain other arrangements that constitute a *Distress Organisation*. The details of this are secret, and cannot be given in this Manual. Nevertheless Captains and Air Navigators should make themselves familiar with the procedure as published from time to time in Air Ministry Confidential Orders and Command Operational Instructions.

CHAPTER XII

APPLIED AIR NAVIGATION

" Are we nearly there ? " Alice managed to pant out at last.

" Nearly there ! " the Queen repeated. " Why, we passed it ten minutes ago ! "

—ALICE THROUGH THE LOOKING GLASS.

Hints to Beginners

1. Navigation must not be thought of as a special branch of flying just because some people make it their whole-time occupation or because a great deal of instruction is put in on the ground before the beginner is asked to practise it in the air. It would completely ruin any game to have to stop every few minutes to read the book of rules : The players must rely on some knowledge if they are to be any good. So also with Air Navigation, which all boils down to a set of not very complicated rules.

* A system of coding used in the air.

These principles are taught on the ground and rubbed home with plotting exercises by instructors, whose close supervision on the ground cannot be extended to the pupil in the air. Indeed it is necessary to give the Navigator a sense of responsibility at the very earliest stage of his flying career, and he soon finds himself in charge of the navigation of an aircraft, with no one to urge him on, or to give help if he should want assistance.

2. Time is precious, particularly during war, and the beginner is strongly recommended not to waste a single opportunity for learning and practising Navigation. On the ground the instructor will have few chances of repeating a lesson, and hence it is much safer for the pupil to own up at once if some point is not understood, rather than to let it slip by, in the hope of catching up later. It is quite useless for the Navigator to go into the air not knowing clearly how to do what he has been ordered to practise. Besides, his instructors would be failing in their duty if he were ever sent up without having been told in detail exactly what his orders are.

3. On the other hand, in the air many opportunities will arise unforeseen by the instructor, by which the beginner can profit to his own advantage. The Air Navigator, for example, will find that on nearly every flight he can practice map-reading. Then again there is really no limit to the number of drift readings he can take on each flight. He can therefore practise finding the Wind to his heart's content. As his knowledge of Navigation extends, he will find that every flight permits his trying out all or nearly all the known methods of fixing his position. He will be able to put his knowledge of meteorology to a practical test, noting the Winds, clouds, visibility and weather and comparing his own observations with those of the Meteorologists.

4. A good start to every flight is to set the aerodrome pressure (obtained from the local meteorological office) upon the pressure scale of the Sensitive Altimeter. The latter should then read zero height. If it does not, the amount of error should be noted for future reference. Before the take-off, however, the pressure scale should be adjusted so that the height of the aerodrome is indicated. For general flying purposes, the height required is that above sea level; and the altimeter will now be adjusted to show this within its limits of accuracy. During each flight it will be making a good habit to check the air temperature at frequent intervals. If the height is kept the same to within 200 ft., comparison of air temperatures gives a useful indication of changing air masses, and large Wind changes. In any case air temperatures are required for computing True Heights and True Airspeeds. By trying for all he is worth in the air, the beginner will gain valuable experience upon which to formulate a sound judgment.

5. In some respects the Pilot is in an even better position at first than the Air Navigator, for he has a little more scope for initiative. To start with, he can spend all his odd minutes practising that accuracy of flying which is so essential to all kinds of Navigation. Unless he is honestly painstaking in his flying, the Pilot will never be free from worry on a solo cross-country flight, and he will make it impossible for others to navigate satisfactorily for him. It is therefore an excellent idea to try keeping a steady compass Course, height and Indicated Airspeed, in all kinds of weather, until these three essentials to accurate flying become second nature. Then he can practice altering Course, until he knows exactly how a compass behaves and has mastered the art of turning faultlessly from one Course to another.

6. All this time the Pilot will be learning how different the ground looks from the air, and how, without a map and a rough idea of his whereabouts, he would often find it impossible to say exactly where he is. It will be some time before he develops a sense of drift. But if the Pilot is naturally observant he will certainly be able, after experience, to tell fairly well the difference between the direction of the aircraft's heading and its actual path over the ground.

7. Pilots and Air Navigators will find themselves thinking more and more in terms of *Time*. Time regulates the duration of every practice solo flight, as those who overstay their allotted practice period learn to their cost. Lack of Time usually prevents the Air Navigator from successfully pinpointing himself in his earlier flights; and for the same reason his first attempts at reading drift are often spoilt. Above all, Time is continually brought into prominence through its relation to cross country flying. It is the Time of Departure and the Time of Arrival at his destination or at intermediate land-marks that the Navigator calculates and records so carefully. Later in his training the full significance of Time in relation to astronomical observation is made clear. For all these reasons Pilots and Air Navigators soon come to regard a reliable watch as the most important navigational instrument.

8. A feeling of being rushed will pursue the Air Navigator throughout his entire training, especially when he is ordered to fly, and it may surprise the beginner to learn that this state of affairs is intentional. In working out navigational problems, accuracy is the first requirement, but it must be accompanied by speed of working. The Airspeeds of modern aircraft leave no margin for delay, and in war, flights must often be undertaken at extremely short notice. It is therefore imperative to be able to draw Tracks and calculate Courses, Ground Speeds, and Winds with the utmost speed. To take off without adequate navigational planning may incur the risk of failure to reach the objective. Thus the ability to prepare for flight in the shortest possible time is a matter of first importance. Throughout their training, Pilots and Air Navigators must learn how to work against time without sacrificing accuracy.

In conclusion the beginner must realise that ground instruction is an essential background for practical Air Navigation ; but his training can only be completed by his own efforts and initiative in the air.

Planning a Flight

9. Every time a flight is ordered, it is with some very definite aim in view, since the Royal Air Force does not indulge in light-hearted joy-riding. Whatever the occasion for the flight, the task is invariably considered and authorised by responsible officers whose duty it is to know what is wanted. Orders are given with the utmost precision, and the air crew is thereby relieved of as much work as possible. All the same, the more intimate details of a flight must invariably be left for the Captain and Navigator to decide for themselves. This calls for what is known as a *Flight Plan*.

10. A Flight Plan is drawn up for every navigational flight on the principle that every minute spent in preparation on the ground saves nine in the air. Maps and charts are carefully collected for the flight and the proposed Tracks drawn upon them and measured. Weather reports are studied and forecasts discussed, if possible with a Meteorologist. A survey is noted of Winds that are likely to be encountered at various stages on the way. Any special hazards, like enemy opposition, high mountain ranges and the position and movement of weather "fronts" are recorded, together with a host of information such as the stars and radio aids that will be available, and the procedure for signals and identification.

11. Having summarised all this information, which is naturally different for each flight, the Navigator enters it in the appropriate spaces on the first and second pages of Form 441, the Navigation Log (see Appendix I). Using the forecast Winds, and True Airspeeds (agreed to by the Captain) he calculates the Courses, Ground Speeds, and Estimated Times of Arrival for the various "legs" of the flight, bearing in mind that these are really no more than a rough guide to subsequent action in the air, because the route may have to be changed, and different winds from those forecast will almost certainly be encountered.

Preparation for Flight

12. No details are too small to be overlooked when preparing for a flight. A good stock of sharp pencils, one or two india rubbers, a penknife in a handy place, a protractor, a pair of serviceable dividers, a long ruler, time-speed scales, the current *Air Almanac*, appropriate volumes of *Astronomical Navigation Tables*, *proformas* as required, Astrograph films, message pads, maps, all must be ready for use, to say nothing of carefully checking the Navigation watch against G.M.T. The Navigator may well regard this equipment like a magician surveying his paraphernalia. It is indeed part of his make-up, and he will feel embarrassed if he cannot put his hand instantly upon its smallest item. By adopting some sort of routine, the Navigator will easily evolve for himself an adequate check against the dangers of last-minute forgetfulness, and if he is provided with a canvas satchel he will find it comparatively simple to keep his stock-in-trade together.

13. While the Air Navigator is engrossed in such details, his Commanding Officer will be anxious to bring more weighty information to the attention of all the members of the crew. So as to ensure that no one, least of all the Captain and Navigator, leaves without fully understanding those aspects of the flight that affect him, a careful briefing is made at which the plan of campaign is discussed, vital and secret information distributed, and questions answered. This conference welds together the action already taken by individual members of the crew, indicating what still remains to be done, and ensuring that no one takes off with a single query left in his mind, and a single item of equipment missing or out of place.

Points Prior to Plotting

14. In order to ensure accuracy and speed when solving vector triangles by graphical constructions it is important for the Navigator to pay attention to the following details, which will rapidly become second nature to him. In all plotting the Arrow Convention is to be strictly adhered to. Air Positions will be indicated by small triangles, D.R. positions by small squares, and fixes by circles, suitably labelled in every case.

- (i) Be provided with a minimum of two sharp pencils, a sharpener and a rubber.
- (ii) Draw clean, thin lines.
- (iii) Be meticulous. When using a protractor make sure that the N—S line is parallel to the chosen meridian. When using dividers, make sure that their points pierce the exact spots on the plot.
- (iv) Make sure that the ruler has a straight edge and that the lines drawn actually follow the desired directions or pass through the proper terminals. If using parallel rulers, or plotting arms, make sure that there is not excessive play in the joints. When taking a direction from a compass rose, make sure that the ruler is aligned with *both* sides of the rose. For example, if a direction of 090° T is wanted, see that the ruler lies across the rose from 090° T to 270° T.
- (v) In all but the simplest constructions, draw a rough sketch beforehand. From this, draw up a plan for the lay-out. This will help to eliminate unnecessary lines which should never be drawn on a plot.
- (vi) Always state the scale of the vectors employed. The scale adopted should be the largest that can be conveniently used. Small-scale figures invariably give bad results. The figures in this Manual are restricted by lack of space.
- (vii) Where there is no obvious meridian, draw a line to which the direction of all the vectors may be referred. **Always Plot in True Directions.**
- (viii) Carefully label all vectors, making full use of the arrow convention. In a diagram involving much drawing it may otherwise be difficult to avoid confusion.
- (ix) Whenever time permits, check back over all the vectors. An error may easily creep into the working unobserved, but may be as easily detected.
- (x) Never work too fast, or errors will multiply. Every beginner will experience the difficulty of adjusting his mental processes to novel requirements, and the first plotting will be fairly laborious. Speed and precision are the reward of constant practice, and are not quickly mustered. It is better to proceed surely at a medium pace than to rush along in headlong confusion.
- (xi) If many diagrams have a common vector, make as much use of this fact as possible. For example, where the True Airspeed is likely to remain unchanged it is a good idea to draw an "Airspeed circle" with the Airspeed vector as radius. Courses in any direction from the centre may then be quickly drawn, especially if the Airspeed circle is centred on a compass rose on the map or chart in use.
- (xii) Diagrams should be well spaced, and set apart from the Courses or Tracks of the aircraft whenever possible. The finished plot should be as satisfying as a well-drawn picture and as accurate as a blue print. It should be so self-evident that any trained Air Navigator could appreciate the situation after only a brief inspection.

Log Keeping

15. The object of keeping a log by the Navigator is to prevent mistakes being made in the air. As a general rule it is dangerous to commit anything to memory, and mental calculations other than simple checks should be avoided at all costs. The painstaking Navigator finds his time fully occupied in making observations to check his progress across country. The data he collects is seldom of value in itself, but in conjunction with other observations, it serves as a guide to future action. Primarily therefore a Navigation Log should be a clear and handy record of Courses, Tracks, Drifts, Bearings, Winds, Positions, Times and so on.

16. The flight may at any time be reconstructed and analysed from a well-kept log. By referring to his log, the Navigator can thus justify any action which he may be asked to explain. Moreover in the event of his being disabled, it will be possible for somebody else to pick up the threads without serious interruption. A navigation log may indeed be used for the following purposes :

- (i) As a record of actual weather experienced.
- (ii) As a record of reconnaissance.
- (iii) As a record of engine and airframe times.
- (iv) As a record of messages and signals.
- (v) As evidence in a Court of Law.

17. The beginner must not think that a log is kept for its own sake. In war time no such waste of paper could be tolerated. It will on the contrary be found that the navigational routine suggested by the lay-out of the Navigation Log (F441) adheres closely to the best navigational practice. By keeping a good log the Navigator almost ensures the success of his flight. This does not mean that a log cannot be faked to make the Navigation appear to be better than it is in fact. Mistakes are bound to occur, and if honestly recorded they can be traced and corrected, both at the time and subsequently in analysis. Besides helping the beginner to acquire sound navigational habits, a log will thus give an instructor a good idea of the pupil's prowess and activity.

18. The following rules have been developed for keeping the Navigation Log (Form 441). By conforming to these conventions, not only will the Navigator record observations almost automatically, but the benefits of a system common to all Navigators will also be enjoyed.

(i) All directions, Tracks, Courses, and Bearings are expressed as three-figure groups, followed by the appropriate abbreviation T M or C.

(ii) All place names are printed in block capitals.

(iii) Figures must NOT be altered. When necessary, they should be crossed out or neatly erased and re-written.

(iv) The first page of F.441 constitutes the Flight Plan, and should be completed as far as possible *before* flight, and kept up-to-date in the air, e.g., E.T.A. and A.T.A. columns.

(v) Units of speed and distance should be stated clearly in the appropriate columns on the second page, and, to avoid confusion, should be uniform throughout. No repetition of units need be made later in the log.

(vi) Alterations of temperature, height, Rectified Airspeed and True Airspeed must be recorded in the appropriate columns.

(vii) ALL Courses flown must be recorded. If the Track and Course remain unchanged, repetition of these is not necessary after the first entry.

(viii) The Distance to Run column records ground distance to fly on each leg, to simplify calculation of Ground Speed, Wind Velocity and E.T.A.

(ix) The application of Deviation and Variation to Compass bearings must be inserted in the columns provided.

(x) Loop readings should be treated in the same way as other bearings taken from the aircraft's head, i.e., the True Course of the aircraft must be added ($- 360^\circ$ if necessary) to obtain the True bearing, all working being shown in the Observation column. In some loops the True Course can be set on the instrument which then gives True bearings. Conversion Angle or Convergency to be shewn in the Observation Column.

(xi) All messages to base are recorded together with their serial numbers, underlined and placed on a separate line on the left side of the Observation column to ensure prominence, e.g., "M.T.B. (1)."

(xii) All E.T.A.s are placed clearly in the column on the right hand side, and underlined, e.g., "E.T.A. 10.33."

(xiii) All Winds found are recorded on a separate line as Wind Direction followed by Wind Speed, enclosed in a box for the sake of prominence, and followed by the method used, e.g., "W/V090°/20 Two Fix."

(xiv) If Time systems other than G.M.T. are ever employed, the zone number or other indication should be placed at the top of each Time column. Fractions of minutes are recorded in seconds.

(xv) ALL weather conditions and changes thereof in flight are recorded in brief in the General column.

(xvi) When recording drift, the method employed, if not obvious, should be stated to indicate reliability.

(xvii) Positions are recorded by one of the approved systems of reference (*See* Chapter I, paragraphs 31—51).

(xviii) Each sheet is signed by the Navigator responsible.

19. Writing is reduced to a minimum by freely employing the following *approved* abbreviations.

<i>Abbreviation</i>				<i>Significance</i>
A/C...	...	...	...	Alter Course, change of Course without change of destination.
A/Comp.	...	...	...	Astro Compass.
Air	...	...	...	Air plot position.
Alt.	...	...	...	Altitude of Heavenly Body.
A.S.I.R.	...	...	...	Airspeed Indicator Reading.
A.T.A.	...	...	...	Actual time of arrival.
Az	...	...	...	Azimuth.
B.B.	...	...	...	Back bearing.
C.	...	...	...	Compass.
C.A.	...	...	...	Conversion Angle.
C.A.S.	...	...	...	Corrected Airspeed.
C.E.	...	...	...	Compass Error.
Co.	...	...	...	Course.
D.R.	...	...	...	Dead Reckoning.
Dev.	...	...	...	Deviation.
E.A.S.	...	...	...	Equivalent Airspeed.
E.T.A.	...	...	...	Estimated time of Arrival.
E.T.I.	...	...	...	Estimated time of Interception.
ft.	...	...	...	feet.
G.P.I.	...	...	...	Geographical position of Interception.
G/S	...	...	...	Ground Speed.
Ht.	...	...	...	Height.
I.A.S.	...	...	...	Indicated Airspeed.
k	...	...	...	Knot(s).
km.	...	...	...	kilometre.
L.G.	...	...	...	Landing ground.
Lt.H.	...	...	...	Lighthouse.
Lt.V.	...	...	...	Light-vessel.
m.	...	...	...	Statute mile.
M.	...	...	...	Magnetic.
M.T.B.	...	...	...	Message to Base. Position signal.
n.m.	...	...	...	Nautical mile.
ϕ	...	...	...	(Greek "phi") Transit.
P	...	...	...	Port.
Posn.	...	...	...	Position.
P/L	...	...	...	Position line.
R of A	...	...	...	Radius of Action.
R.A.S.	...	...	...	Rectified Airspeed. Indicated Airspeed corrected for instrument and position errors.
S	...	...	...	Starboard.
S/C...	...	...	...	Set Course (at beginning of each "leg").
T.	...	...	...	True.
T.A.S.	...	...	...	True Airspeed. Rectified Airspeed computed for height and temperature.
T.M.G.	...	...	...	Track made good.
Tr.	...	...	...	Track.
T.T.T.	...	...	...	Time to turn.
Var.	...	...	...	Variation.
W/D	...	...	...	Wind Direction.
W/S	...	...	...	Wind Speed.

<i>Abbreviation</i>	<i>Significance</i>
W/T GO	W/T contact with Base has been established.
W/V	Wind Velocity.
'	Symbol for minute of arc and nautical mile.

In addition, abbreviated meteorological terms, and abbreviations of which the meanings are obvious (e.g., "St. CATH. PT." for "ST. CATHERINE'S POINT") should be used.

Message Chits

20. It has been found by bitter experience that verbal communication between members of the crew is a very dangerous medium for passing navigational information because of the possibility of misunderstanding. It is, for example, not unknown for a Pilot to steer, say, 125° after being asked by the Navigator by telephone to set a Course of 025°. The mistake may not be discovered until the aircraft is lost, and the Navigator is then faced with an unpleasant surprise that is largely his own fault for not writing his instructions down in black and white and supervising their execution.

21. Apart from the danger of misunderstanding, extreme annoyance can be caused by having instructions bawled above the noise of the engines. Message pads are thus provided and are much better than odd scraps of paper. They should be dated, given a time of origin, and a serial number. After action is taken on them, the chits should be returned to the originator to facilitate subsequent reference if necessary.

22. The Navigator normally uses message chits in the following circumstances :—

- (i) At the beginning of each leg, to give the Course to steer for the next position, and the E.T.A.
- (ii) Whenever a position signal is made.
- (iii) When necessary to alter Course, or E.T.A., the new Course to steer, or E.T.A. being stated.
- (iv) When necessary to warn the Captain of danger or prohibited areas ahead.
- (v) When instructing the Wireless Operator to obtain loop or D/F bearings, detailing the probable bearings of certain stations.

Messages to Base

23. Any member of the crew may originate a message to base, but no message may be sent without the authority of the Captain, who MUST be shown all messages, both "out" and "in." The Navigator is responsible for drafting position signals and messages concerning changes of route. Preservation of wireless silence in war restricts the occasions when messages may be sent to those times detailed in the orders. Non-observance of these orders may not only spell disaster to the offending aircraft but also have more serious consequences.

Navigational Duties of Members of the Air Crew

24. Operational flying steadily grows more complicated, and what was formerly the work of the Pilot is now divided between the specially trained men that make up the crew of a modern aeroplane. The single-seater fighter, with its jack-of-all-trades Pilot is the sole reminder of a bygone age ; and even here the Pilot's limitations are recognised, and ingenuity has relieved him of many navigational problems. In all other aircraft the Navigator has become an essential member of the crew. Aircraft design may have been slow to accept this fact and the Navigator may still have to work in a cramped space, surrounded by obstacles, out of reach of his instruments, his vision of the ground impeded by mainplanes, struts, cowlings, or simply by the lack of windows. He, more than anyone, has continuously to use his head, and consequently a good navigational lay-out can relieve him of much trouble. Ideally the Navigator should be provided with a large plotting table, well lit by day and night ; handy and ample stowage for maps, plotting instruments, and publications ; windows giving all-round views of the ground ; an accessible dome for astronomical observation ; proximity to both the Pilot and Wireless Operator to facilitate supervision of Courses and delivery of message chits ; and ability to use a drift sight, bearing compass, astro-compass, sextant, and loop without leaving his seat.

25. Considering the speed with which he has to work, and the unavoidable strain imposed by noise, cold, vibration, partial lack of oxygen and the anxiety of enemy opposition, the accommodation provided for the Air Navigator may compare unfavourably with the Chart Room of a tramp steamer.

The Navigator of a large aircraft has therefore sometimes to rely on the help of other members of the crew, whose co-operation is often essential to success. The navigational duties of the members of a multi-crew aircraft are generally as follows :—

The Navigator.—

26. (i) Thorough preparation for each flight.
- (ii) Synchronises Pilot's and Wireless Operator's watches with his own, checked against G.M.T.
- (iii) Gives the Pilot Compass Courses to steer, written on message chits. *Checks that the Pilot sets the correct Courses on his compass.*
- (iv) Keeps the Navigation Log.
- (v) Keeps a plot of the flight.
- (vi) Makes all necessary observations to ensure accurate Navigation. Notes all changes of temperature, height, True Airspeed. Takes frequent drift readings. As often as occasions demand pin-points the aircraft, visually wherever possible. Checks Wind Velocity regularly and especially near the Target area, using the most appropriate methods.
- (vii) On request gives the position and E.T.A. to the Captain without undue delay.
- (viii) Makes out all position signals for the approval of the Captain.
- (ix) Notes all weather changes in flight. On request, advises Captain regarding action to counter unfavourable weather conditions.
- (x) When appropriate keeps a reconnaissance report supplemented by photographs.
- (xi) Initiates requests for D/F bearings. When the D/F loop is used, the probable bearings of the best situated stations should be given as a guide to the loop operator. When D/F stations are used, the Wireless Operator should be informed which stations are most likely to provide a satisfactory fix.
- (xii) Informs the Pilot whenever drift, sextant, astro-compass and D/F loop observations begin and end.
- (xiii) Asks the Rear Gunner for back-bearings when necessary.
- (xiv) Co-ordinates the efforts of other members of the crew when map-reading under difficulties.

The Pilot.—

27. (i) Provides himself with topographical maps required for the flight, and marks the proposed Tracks. Prepares a summary Flight Plan.
- (ii) Checks his time with the Navigator.
- (iii) Before taking off, sets the sensitive altimeter to the height of the aerodrome.
- (iv) Keeps a brief log of the flight.
- (v) Sets Compass Courses when directed by the Navigator. Ensures that such Courses are actually steered.
- (vi) Informs the Navigator of all but purely transitory changes of Course, Height, or Indicated Airspeed.
- (vii) When drift is being measured, when D/F loop bearings are being taken, and particularly when astronomical observations are being made, rigidly maintains a constant Course and Airspeed. If necessary climbs to a layer free from bumps. (The accuracy of such observations depends almost entirely on the Pilot's ability to fly straight and level.)
- (viii) Assists the Navigator in map-reading and reconnaissance when necessary.

Wireless Operator.—

28. (i) Prepares for each flight a full list of W/T D/F facilities, locations, times of operation, frequencies, call signs, effective ranges, and procedure.
- (ii) On request, endeavours to call up those D/F stations indicated by the Navigator.
- (iii) On request, must be prepared to operate the loop, and should be helped by the Navigator, who indicates the probable bearings of certain stations.
- (iv) Advises the Navigator which stations are available at any particular time. Identifies stations for the Navigator.

Rear Gunner.—

29. On request, takes back-bearings of objects over which the aircraft has passed without a subsequent change of Course. He should be able to map-read and should make full use of his unrestricted view so as to help the Navigator.

Bomb Aimer.—

30. Acts in close liaison with the Navigator and Pilot when map-reading in the Target area. Takes drift when required.

The Captain of Aircraft.—

31. (i) Supervises the navigational duties of the crew both on the ground and in flight. Advises the Navigator in preparing the Flight Plan.

(ii) Ensures that all equipment is in order, and all necessary information is taken on board.

(iii) Qualifies himself by training and experience to take over from the Navigator should the latter become a casualty.

(iv) Keeps a brief log.

NAVIGATION TECHNIQUE

Measuring Drift

32. Drift must be measured at frequent intervals in flight because :—

(i) It determines the Track made good. (e.g., If drift is 9° P when the Co. is 005° T, the T.M.G. = 356° T).

(ii) It acts as a simple check of Wind Velocity. If the drift measured does not correspond with the calculated drift, the actual Wind Velocity must be different from that expected. If the drift measured does correspond with the expected drift, Wind Velocity may nevertheless have changed (*see* Chapter V, paragraph 57).

(iii) It is a means of determining actual Wind Velocity. Methods of finding the Wind by drift measurement are described in Chapter V.

Drift measurement requires a view of the ground, at least some characteristics of which must usually be discernable. When haze, darkness, or lack of features (i.e., desert) prevents the Navigator from choosing recognisable objects, a discontinuity of ground tones may provide a distinct enough reference point. Similarly, when flying over the sea, white-caps, and thinly covered shoals enable accurate drift to be measured. High magnification, giving a streaky view of the ground or water, affords an excellent means of measuring drift. The same effect is obtained by low flying, when over the sea.

33. In the absence of stationary objects on the ground, a moving object over which the aircraft has directly passed may be used. The drift thus obtained is a *relative drift*, being the angle between the Course and the line of constant bearing (the relative Track). True drift can only be obtained if the velocity of the moving object is known. The choice of moving objects, such as the lights of cars by night, is, therefore, of little practical value.

34. On dark nights it is impossible to see objects on the ground clearly enough for drift measurement, unless they are lit artificially. Four-pound incendiary bombs and reconnaissance flares are very useful at such times, though the former may fall so far behind that no one but the Rear Gunner may be able to make any use of them. Excellent drifts are nevertheless obtainable.

35. Over the sea, aluminium patches, smoke floats and (for night work) flame floats are provided. These all have large trail angles, which make it difficult and often impossible to obtain back-bearings when visibility is restricted. Their ballistics are at present being improved.

36. Drift may be obtained by any of the following visual methods :—

(i) *Drift Recorder Mk. II* (*See* A.P. 1275B). This is a short periscope that gives a wide field of view of the ground. Any significant ground object is followed across the field of view by a manually-operated pointer. In so doing a pencil trace is made of the object's movement on a bearing plate, from which the drift is instantly read. The instrument is designed for mounting near the Navigator's seat, and requires very little skill in operation.

(ii) *Course-Setting-Bomb-Sight.* The instrument is levelled and the Drift Bar is adjusted so that objects on the ground pass down the drift wires. The drift is then registered by the Wind Gauge Bar directly against the Drift Scale. The sight can only be used on *approaching* objects, though these can be slightly to one side or the other. It is important to brace the head into a steady posture for an accurate observation to be made. Several objects should be chosen and followed the complete length of the drift wires, if possible.

(iii) *By Back-Bearing.* If an accurate bearing is obtained of an object over which the aircraft has passed without subsequent alteration of Course, the angle between the reverse of this back-bearing and the True Course is the drift. Thus if the Co. is 205° T, and the back-bearing obtained is 018° T, the Drift = $(018^{\circ} \pm 180^{\circ}) - 205^{\circ} = 198^{\circ} - 205^{\circ} = -7^{\circ}$, or 7° P.

Back-bearings may be obtained visually by :

- (a) Astro-compass (used as a bearing plate).
- (b) Hand Bearing Compass (0.6). Care must be taken to use this in a position free from local magnetic interference.
- (c) Calibrated Rear Gun Turret. The gun-mounting having been calibrated in degrees, the gun is trained on objects over which the aircraft has flown. Good drift readings by the Rear Gunner depend on co-operation between him and the Pilot, who must fly as steadily as possible. With a very little training, excellent results are obtained both by night and day.
- (d) Tail markings. These are useful when other means are not available. With the aid of a bearing plate or hand bearing compass, the angles subtended at a selected observation point in the aircraft between the fore-and-aft line of the aircraft and significant parts of the tail unit (e.g., king posts, trimming tabs, rudders, fins and struts) that are visible from the observation point, are measured, and noted for reference in the air. The Navigator who observes that an object which was previously beneath the aircraft now appears to be just below the tip of the Port tail plane will, therefore, know that this represents a given drift to Starboard.

In addition to the foregoing direct methods of measurement, drift may be obtained by deduction from a knowledge of the Track made good, and of the Course steered. Methods of determining the Track made good will now be discussed.

Determining the Track Made Good

37. Calculated Courses, Ground Speeds, and E.T.A.s only hold good while the Wind Velocity and True Airspeed remain stable. Wind Velocity unfortunately changes continually and hence the Track made good by an aircraft rarely remains the same as the required Track for any length of time. The Navigator naturally wants to get from place to place with the least possible delay. It is an important matter, therefore, to discover whether or not the required Track is being followed ; and, if not, what exactly is happening. The Track made good can be found in the following ways :—

(i) By two fixes. The Navigator fixes the aircraft's position on setting Course. After an interval of time, and without changing Course, he fixes position a second time. The Track between the two fixes is measured on a map. This gives the Track made good, provided the two fixes are accurate. The reliability of fixes is discussed in Chapter VI. Upon it depends whether or not the Track made good is represented by the line between the fixes.

(ii) By measuring drift and applying it to the True Course. Thus, if the Co. is 356° T and the Drift is 10° S, the T.M.G. is $(356^{\circ} \text{ T} + 10^{\circ} =) 006^{\circ}$ T.

(iii) By reversing a back-bearing. When a bearing is obtained of an object over which the aircraft has passed without subsequent alteration of Course, that bearing is the reverse of the Track made good. Thus a back-bearing of 165° T gives a Track made good of $(165^{\circ} \text{ T} \pm 180^{\circ} =) 345^{\circ}$ T. Visual methods of obtaining back-bearings have been described above. They may also be obtained by D/F methods, as follows :

If the aircraft has flown directly over a Radio or D/F Station (e.g., a beacon or homing D/F installation at the aerodrome of departure) without changing Course, a bearing obtained by loop, or ground D/F, will indicate the Track made good.

The limitations of D/F accuracy have been discussed in Chapter IX. Furthermore, the curvature of the position lines so obtained, and discussed in Chapter VI, paragraphs 30—55, introduces practical difficulties. It follows that the Track made good can only be determined

accurately by such D/F methods when within fairly close proximity to the station. Thus, 20 minutes after leaving his base, a Navigator obtains a loop bearing of 216° T from the station beacon. The estimated Ground Speed is, say, 240 k, which puts the aircraft within 100 n.m. of its base. The Navigator calculates the conversion angle to be less than one degree. He may feel fairly confident in accepting the Track made good as being the reverse of the loop bearing, namely, $(216^\circ \text{ T} \pm 180^\circ =) 036^\circ \text{ T}$, even though a coast-line may intervene between him and the beacon.

(iv) By three or more position lines obtained from one or more origins. This is described in Chapter VI, paragraph 27.

Measuring Ground Speed

38. The Navigator wants to know the Ground Speed in order to time his arrival at his destination and at intermediate points *en route* or to determine the distance run along a Track in a given time. The calculated Ground Speed is rarely exactly experienced during a flight of any length, mainly on account of changes in Wind Velocity encountered. Since Ground Speed is also one of several clues for finding Wind Velocity (*see* Chapter V) the Navigator is keenly uninterested in its measurement. This can be done in the following ways :—

(i) By two fixes. Just as the Track made good may be measured between two fixes, so Ground Speed may be measured by observing the Time between two fixes. The accuracy of the fixes is reflected in the accuracy of the Ground Speed so found. For a given degree of accuracy of the fixes, the further they are apart, the truer will be the Ground Speed, though such a Ground Speed may not be representative of actual conditions at either fix. For example, an aircraft is observed to have travelled 240 n.m. in 45 minutes. The Ground Speed of 320 k can only be regarded as an *average*, and may be substantially different from the actual Ground Speed at the 45th minute, since the Wind Velocity may have changed considerably over 240 n.m.

(ii) By measuring the distance between two position lines that cut the Track at right-angles, or nearly so, the time-interval being known. This method is discussed in Chapter VI, paragraph 12 (ii).

(iii) By Drift Recorder Mk. II. (*See* A.P. 1275 B). The operation of this instrument has been briefly described in paragraph 36 (i) above. The length of the pencil trace on the bearing plate is directly proportional to the length of Time of the observation and speed of movement of the object, while it is inversely proportional to the height of the aircraft above the object. By timing the movement of an object between the grid lines by means of a stop-watch, and knowing the height above the object, i.e., true height of aircraft *minus* height of object (taken off the map), the speed can be found by referring to the specially-constructed circular slide-rule mounted on the instrument. This method suffers from two serious defects :—

(a) The height above the object selected is almost impossible to find accurately, even when flying over the sea. Accurate Ground Speeds cannot be expected if the object is much less than 5,000 ft. below the aircraft.

(b) The period of measurement is comparatively short, depending on the speed of the aircraft and its height above the ground. In this short time the Pilot may be climbing or diving, and the Airspeed may not be representative of the average True Airspeed. Several repeated observations are, therefore, required to obtain a representative Ground Speed.

(iv) By Timing Bead Method. This method employs the Course-Setting Bomb-Sight. The instrument is levelled, the height above the ground is set on the Height bar, the terminal velocity is set to infinity, and the Drift bar adjusted until objects on the ground pass exactly down the Drift wires. By looking closely through the back sight on the Height bar, the passage of objects from one bead on the Drift wires to the next is timed by stop-watch, and an average of several readings obtained.

The distance between consecutive beads, with the sight properly set, is equivalent to one statute mile (Mk. IX A) or one nautical mile (Mk. IX C). Hence the time in *seconds* to cover this unit distance is similar to the time in *minutes* to cover 60 such units. Graduations on the drift bar provide a handy conversion scale for Ground Speeds.

The timing bead method suffers from the same two defects as the Drift Recorder Mk. II, and in addition is more cumbersome. It is seldom used with success, particularly at low levels.

Measuring Wind Velocity

39. Methods of wind-finding are described fully in Chapter V. To be wholly acceptable, the method adopted must interfere least with the operational conduct of the flight, and yet must be capable of giving accurate results. As a general rule the simplest methods are the best, particularly if little or no plotting is required.

Unquestionably the best method is to take multiple drifts (when feasible) in quick succession. The Wind thus found has the important quality of being almost up-to-the-minute, and can be used for immediate action. The method also provides its own check on accuracy.

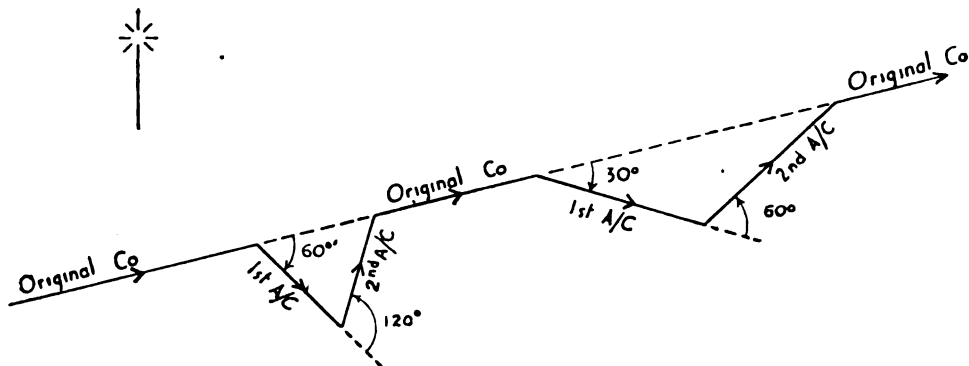


FIGURE 1. The Multiple Drift Method of Wind-finding Applied Operationally.

The Multiple Drift method is readily applied to operational flying without undue loss of flying time. Thus on a straight flight to an objective, the first drift may be taken on the Course already set. An alteration of Course by 60° to either port or starboard is then made, the second drift taken, and the time flown during the observation noted (usually about 2 minutes, though tail drifts by the Rear Gunner may take longer).

Course is now altered 120° in the *opposite* direction to the first alteration and drift is again observed. After an equal interval of time on this Course, the original Course is resumed, and, if considered desirable, drift checked on this Course again.

Since the aircraft has flown round the sides of an equilateral triangle, its Air Position on resuming the original Course is exactly where it would have been had no alteration taken place, except that it arrives later at that position by the amount of time spent on *one* side of the "dog leg."

In the case of a formation of three aircraft, the wing aircraft may be detached 60° to port and starboard, and drift observed by all three simultaneously. The leader may afterwards throttle back to enable the others more rapidly to rejoin him.

If it is not desirable to leave the original Course by such a distance as described, the first Course need be altered by, say, only 30° , to port or starboard, and the second by twice this amount (60°) in the opposite direction. The resulting drifts may not produce quite so satisfactory a "cocked hat."

The air plots involved are illustrated in Figure 1, where the two cases described above are shown diagrammatically.

40. The Air Plot method yields the next best results, provided reliable fixes (e.g., pin-points) are employed, and they are not too far apart. Over distances exceeding 100 miles, the Wind found will only be the *mean* Wind, which may have little practical value for the future conduct of the Navigation, since it may have little resemblance to the Wind experienced in any particular region. D/F or astro-fixes are rarely accurate enough for wind-finding, and should only be accepted with great reserve, when other fixes are unobtainable.

41. In light Winds in summer time there is a breeze from sea to land by day and from land to sea at night. The effect of this does not extend above 2,000 feet. Thus a change of Wind is often experienced in summer in the vicinity of a coast-line.

42. A word of warning is given against the fallacy of accepting the forecast Wind as being usually correct. Even in the British Isles, where close observation of the weather is possible, there are many occasions when the Winds actually experienced differ largely from those forecast. In other territories, where meteorological information is less abundant, forecast Winds seldom agree in detail with the Winds found. Therefore while it is sound navigational practice to plan a flight in full, using forecast Winds as

a guide, the Courses, Ground Speeds and E.T.As. thus calculated must not be accepted as final, and alterations should certainly be expected in flight.

43. The change of Wind with height is often complex and above the lowest 2,000 feet there are no hard and fast rules, except that westerly Winds generally increase with height and easterly Winds decrease and may even die out, to be replaced by westerly Winds. In the lowest 2,000 feet, over *land*, the Wind *always veers*, generally by 20° to 30° , while the speed increases. Over the *sea*, the Wind in the lowest 2,000 feet normally veers with height, but the average value of the veer is only about 10° . A few cases of Winds *backing* with height in the lowest 2,000 feet have been observed over the sea.

Moreover, there is no justification in assuming that because the Wind found, say, at 2,000 feet differs by so much from the Wind forecast at that height, therefore the Wind at 10,000 feet will differ equally from that forecast for 10,000 feet. The vertical structure of the atmosphere is very complex and there is no hard and fast relationship between Upper and Lower Winds. As a general rule the Wind at 1,500 feet blows from a direction about 10° more than that of the surface Wind, but as has been said, under certain conditions the Wind may not *veer* in this way, but may even *back*. Beyond this rather vague tendency there is no known simple and concise law connecting Winds at different levels.

Fixing Position

44. The various means available to the Navigator for fixing his position have already been described. The position of an aircraft should be fixed frequently so as to keep the errors accruing from D.R. Navigation (10 per cent. of the air distance flown) within narrow *absolute* limits. The frequency of the fixes depends upon prevailing conditions.

45. A flight in good visibility over a region abounding in excellent land or sea marks does not require much careful checking of position, since this can be readily observed whenever desired. A flight in poor visibility over a region of few distinctive features is most satisfactorily navigated by making full use of whatever fixes are available. On a long flight, when the ground or sea is obscured, fixes should be obtained by D/F or astro methods at regular, but not too frequent, intervals, the Navigator saving his energy for the more exact Navigation required towards the end of the journey. As the aircraft approaches its base, an accurate fix should be obtained about one hour before E.T.A. and a careful check made of Track made good. Failing visual methods of fixing position, full advantage should be taken of any D/F homing facilities at the base.

46. The methods available for fixing position are summarised in order of reliability under all circumstances :—

(i) *Visual fixes* are best, but are often not available owing to bad visibility, clouds, fog, darkness or simply lack of prominent ground features. They are obtained from :—

(a) Map-reading.

(b) Visually-observed position lines.

(ii) *Astro fixes*. The average Navigator, using a bubble sextant and assisted by a skilful Pilot, can easily obtain a position line of an accuracy within ± 10 miles. Using a marine-type sextant (when possible) the Navigator can indeed often obtain almost exact position lines. Equipment is in development to improve results under all conditions of observation.

When using two such position lines, nearly at right-angles to each other, a fix is obtained accurate to within 12 miles. Astro fixes are only possible when the sky is at least partly clear, and when two position lines are obtainable.

(iii) *D/F fixes*. These suffer from the many defects already described in Chapter IX. In ideal conditions and when the distances involved are not great, D/F fixes can be very accurate. It should however be remembered that a First Class bearing is only accurate to $\pm 2^{\circ}$. Thus at a range of, say, 300 miles, the best position line has a possible error of ± 10 miles. If this is used with a second bearing of equal accuracy, but inclined at only 30° to the former, owing to the shortness of the effective base line, the "diamond" of position may be no less than 60 miles long. The average D/F fix has an error of about 20 miles.

If a D/F loop is used, the accuracy of the bearings is difficult to assess, particularly at great ranges. Moreover when the origin is off the map in use, the plotting of such bearings is not easy.

D/F fixes are popular because of the ease with which they may often be obtained ; but too much reliance is commonly put on them without due regard to circumstances. At times when fixes are desperately wanted, the ground D/F organisation will be congested by other similar requests, and fixes will not, for this reason, be forthcoming without serious delay.

NAVIGATIONAL PROCEDURE

General

47. It is impossible to lay down definite rules concerning the procedure to be adopted by the Navigator in all the various circumstances of flight. The following generalisations must be accepted only for guidance.

Navigators should use every possible occasion to practice their art. It is not sufficient to reserve certain practices only for those times when they are absolutely necessary. While flying in perfect weather over a familiar route, only very elementary Navigation may be required. Again, on many occasions D.R. Navigation can be checked most easily and quite satisfactorily by visual or D/F fixes, and astro fixes may not be wanted. Yet unless the Navigator retains his skill in all aspects of his work, by frequent and deliberate practice, he will lack that confidence and self-assurance necessary when conditions are less favourable and give rise to anxiety. *For all flights always set the altimeter to the height of BASE airfield above m.s.l. before take-off.*

Track Crawling

48. When there are no facilities for plotting in flight, or when, as in a patrol or search, the aircraft must adhere to a definite Track, and finally when the routeing is of the simplest nature, maintenance of the required Track, commonly called *Track Crawling*, is an accepted procedure.

The advantages of such a method are that, provided visibility permits frequent pin-pointing and checking of drift, a destination will eventually be reached, or a specified area will be searched.

The Wind may most suitably be found when Track Crawling by

- (i) Track and Ground Speed method over the land.
- (ii) Drift and Wind Lane method over the sea.

These methods and their limitations are fully described in Chapter V.

The disadvantages of Track Crawling are that in the absence of good visibility and good fixes, no check can be kept on Ground Speed nor on Wind Velocity. Moreover, if the Pilot alters Course, perhaps without fixing position at that time, it may be laborious if not impossible to calculate a position at any subsequent time, or a Course to make good any newly-required Track.

It is therefore not at all suitable if poor visibility is likely to be encountered, or when the ground is obscured in flight.

Air Plotting

49. Unless absolutely impossible, an Air Plot should be kept in flight, particularly when a multiplicity of Courses are being flown. The advantages of an Air Plot are :—

- (i) It is easy to keep and is subject only to errors of draughtsmanship.
- (ii) The Air Position can be quickly determined from it.
- (iii) If the Wind is known, the D.R. position can be found, when required, by laying down the Wind effect from the Air Position appropriate to that Time.
- (iv) If the Wind is not known, it can most easily be found by comparing the Air Position with a fix at any time. Any method may however be used without spoiling the Air Plot.
- (v) It promotes a keen interest in checking True Airspeeds, Courses, and Times.
- (vi) It gives the Pilot the greatest possible freedom of action, so necessary in operational flying when maintenance of a Track is impracticable in the face of enemy opposition.

It is a good plan to re-start an Air Plot every time an accurate fix is established. Errors of plotting are thereby reduced to a minimum.

Low-Flying Navigation Over the Land

50. Preparation is the secret of successful Navigation never more than when an aircraft is flown just above ground level. The view is severely restricted, the Pilot is unable to fly steady Courses, or Airspeeds, drifts cannot be measured, astro observations are impossible, H.F. D/F ranges are severely restricted, and the trailing W/T aerial cannot be reeled out. Close-up pin-pointing alone is possible and then only when significant objects may be seen. Because low-flying over the land has certain tactical advantages by day, the Navigator must be aware of its special problems.

51. In preparation for the flight, the route must be carefully chosen to afford ample checks for map-reading, and yet preserve the elements of surprise and protection which are sought in flying low.

52. There is no chance of plotting during low-flying, and once it begins, topographical maps must be used. Having marked the route clearly on the maps, the physical features must be carefully studied and visualised. They will be in view from the aircraft for such a short time, that they may easily be missed altogether unless actually anticipated. This applies also to such special dangers as high-tension cables and *cul-de-sac* valleys, which must be foreseen.

53. To help check the aircraft's progress and position, it is advisable to mark the Track to be followed, say, every 10 miles; or, better still, decide with the Pilot what the average True Airspeed will be, and, by calculating probable Ground Speeds on the various legs of the flight, mark the Track into time-intervals showing, for example, every 5 minutes. A Time and Speed Scale is useful in this preparation. Then, in flight, reference to the Time alone will indicate on the prepared map the probable position of the aircraft.

54. Low-flying over land therefore limits the scope of Navigation severely. Since such flying cannot safely be adopted when the ground is obscured by fog or cloud, the Navigator will always be able to see the ground for map-reading.

Medium Height Navigation

55. Much flying takes place in war at medium heights (500 feet–10,000 feet) either because it is necessary to keep within sight of the ground for reconnaissance purposes, or because meteorological conditions prevent the aircraft from flying at greater heights.

56. On nearly all occasions when flying at medium heights, the ground will be visible, at least intermittently. Drifts may usually be obtained and Winds checked with a high degree of accuracy. Pin-pointing is also feasible; while position lines may often be obtained by any method desired. Moreover Wind Velocities are easiest to forecast for such heights.

57. It follows that in many respects such flying offers the best prospects for accurate Navigation. All the same, it is at medium heights that the worst meteorological, topographical and enemy hazards are encountered; and hence the Navigator may, according to prevailing circumstances, be forced up or down. Even in the interests of Navigation this may be necessary, for astro observation will often be restricted by high cloud or spoilt by bumpy air at medium heights; while the effective range of D/F is less than when flying at greater heights. On approaching a destination, it is best to have an uninterrupted view of the ground, which may mean descending to a low level. This naturally does not apply to occasions where a blind approach is necessary.

58. To sum up, medium heights offer considerable scope for accurate Navigation which is less dependent upon pin-pointing than when flying low. Opportunities will be excellent for plotting, and for frequent accurate visual checks of position, though astro and D/F fixes will often be unobtainable.

High-Flying Navigation

59. At heights in excess of about 10,000 ft. the Navigator is encumbered with oxygen apparatus and heating troubles, and must be prepared to navigate out of sight of the ground. He is often unable to obtain drifts and visual fixes, but on the other hand he may be above bad weather and more frequently have an unimpeded view of the sky. Excellent astro observations are thus more often obtainable. In addition, effective ranges of D/F facilities are greatly extended.

60. At great heights, the Wind Velocity is difficult to forecast with certainty. Such Winds usually have very high speeds, for example, a Wind speed of 100 m.p.h. is quite common at 30,000 ft. Inability to check Wind Velocities at great heights on account of the ground being obscured is a serious matter, because the possible errors are so very great.

61. It follows that though under ideal conditions such Navigation need be no less accurate than at a lower level, it is as a rule limited in accuracy to the astro or D/F fixes by which it must often be conducted. The Navigator is mostly concerned with general tendencies, and in order to ensure reaching a destination, he must often rely upon being led in by D/F homing facilities if he cannot descend to a level from which map-reading is possible.

Navigation on a Climb or Glide

62. When changing height by climbing or gliding, a Pilot often alters the Indicated Airspeed. At the same time the aircraft passes through different layers of air, each having its own particular Wind Velocity. To save time and petrol, an aircraft is seldom climbed to operational height over the point of departure, since the Navigation on a straight climb or glide can be accurately carried out, provided the following precautions are taken :—

(i) The Pilot agrees to fly at a certain Indicated Airspeed during the climb or glide until an agreed height is reached, or until certain conditions are fulfilled, e.g., clouds are cleared.

(ii) The Navigator computes the True Airspeed for the Rectified Airspeed at the mean height of the climb or glide.

(iii) The Navigator finds the Wind Velocity appropriate to the mean height of the climb or glide. This may present some difficulties. Upper Winds are forecast for various levels and stages and the Wind for the particular mean height may not be available. The calculation of the mean Equivalent Wind Velocity is described in Chapter II, paragraph 33.

(iv) A Course is set during the climb or glide to make good the required Track using the mean Equivalent Wind and the mean True Airspeed. At the end of the manoeuvre the Course is adjusted for the True Airspeed and the Wind prevailing at the new level.

Changes of Wind During Tactical Navigation

63. It may be generally stated that changes of Wind Velocity have less effect on the tactical performance of high-speed aircraft than on that of low-speed aircraft. Small alterations of Wind Velocity can be successfully countered by suitable alterations of True Airspeed. This is apparent from a study of Figure 2, which is designed to show the effect of Wind on the radius of action of an aircraft possessing a given endurance.

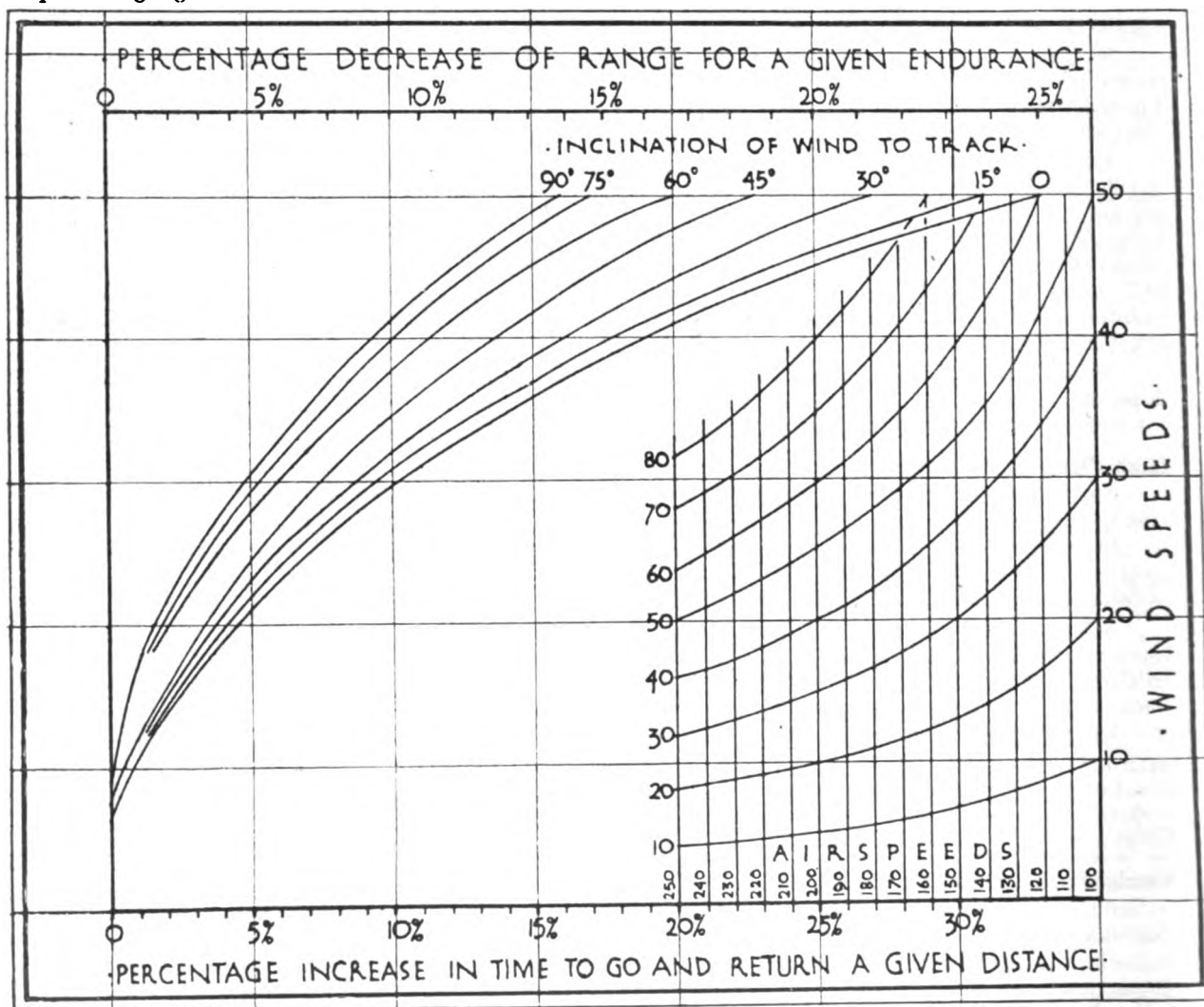


FIGURE 2. Effect of Wind on Radius of Action.

64. Consider the effect of a change of Wind Velocity from a Wind of 40 m.p.h. inclined at 60° to the Track, to a Wind of 50 m.p.h. inclined at 45° to the Track.

Enter the right-hand bottom of the table with the aircraft's True Airspeed, say, 150 m.p.h., and follow the vertical line up to the 40 m.p.h. Wind Speed curve.

Now follow across to the left on a horizontal line to meet the curve of Wind inclination of 60° . The vertical line through this point is now followed to the top of the table, where it is seen to correspond to a 4.3 per cent. decrease of range for the given endurance in still air.

The comparable figure for the new Wind Velocity at the same Airspeed is a decrease from still air range of 8 per cent. But by following the original 4.3 per cent. line vertically down until it meets the 45° inclination curve and thence across to the Wind Speed curve for 50 m.p.h., it will be found that an Airspeed of 210 m.p.h. gives the same results as previously was obtained with an Airspeed of 150 m.p.h.

65. The issue is confused by the decrease of endurance corresponding to an increase in Airspeed, each type of aircraft having its own characteristic behaviour. While therefore it cannot be laid down that in all circumstances the changes of Wind Velocity could be countered by changes of Airspeed, it is possible for Staffs directing operations to calculate the most satisfactory Airspeed for a particular exercise.

66. The most practical general conclusion to be drawn from a study of Figure 2 is that the choice of the most suitable height is of utmost importance for an operation of the radius of action type, in order to benefit from the most favourable Wind.

Action by the Navigator when the Wind Changes

67. In the event of a change of Wind Velocity being experienced while on a tactical exercise, action should be taken to ensure that the primary object of the flight is maintained. If the aircraft is engaged on patrolling a certain track for as long as possible, as in a radius of action, the specified Track must at all costs be maintained by suitable alterations of Course. If the aircraft is engaged on interception duties, the interception must be successfully achieved. This does not mean that the Wind change can be ignored; the action of the Navigator depends upon the prevailing circumstances, as follows:

Change of Wind During Radius of Action

68. If a change of Wind is observed, Course must be altered to maintain or return to the Track ordered as quickly as possible.

The time of the wind-change is noted or estimated as occurring at some *point* on the Track.

If the aircraft is outward bound, a new radius of action should be calculated for the total time remaining, after subtracting the time out to, and back from the wind-change point.

If the aircraft is on the homeward flight to a fixed base, the new Course, new G/S and new E.T.A. must be calculated from the wind-change point.

If the aircraft is homeward bound to a moving base, a new interception should be calculated from the wind-change point, giving a new Course, new Ground Speed, and a new E.T.I. In practice, this is modified by the considerations detailed in paragraph 69.

Change of Wind During Interception

69. When a new Wind is experienced during an interception, the wind-change point should be determined and a new interception calculated from this point, giving a new Course, new Ground Speed and new E.T.I. This entails considerable plotting and time may not permit such elaborate action. Consequently, the following action is recommended as being far more practical.

Provided the original interception Track is maintained, the aircraft will cross the Track of the objective either *earlier* or *later* than the original E.T.I., according to whether the new Wind has increased or decreased the Ground Speed.

The Navigator should ensure that the original interception Track is maintained by frequent drift readings and suitable alterations of Course.

Flight over the land provides continuous checks on Ground Speed. Over the sea ample evidence of wind-change is provided by a study of the sea surface (*see* Chapter V, paragraph 55). Consequently the effect on Ground Speed may be readily calculated.

70. According to the change in Ground Speed, the new time of arrival over the Track of the objective is calculated. If this is earlier than the original E.T.I., the aircraft is then ahead of the objective and should be steered to meet it along its Track. If the new time is later than the original E.T.I., the aircraft is behind the objective which should then be overtaken along its Track.

Pilot Navigation

71. Conditions vary considerably in which Pilots may have to navigate their own aircraft. Generally speaking, there is but little scope for initiating action while in the air, and for this reason successful Pilot-Navigator depends to a large extent on thorough preparation *before* flight.

While flying his aircraft the Pilot cannot handle complicated instruments, or make more than the briefest notes, or pore continuously over a map; yet a knowledge of the theory and practice of Air Navigation is of inestimable value to him and will enable him to make efficient estimations of, and adjustments to his Course, etc., that would otherwise be no more than guesswork.

Map-reading is particularly important to the Pilot-Navigator because he must keep a frequent and careful check of his position, restricted as is his application of Dead Reckoning. He will only be able to refer to the map for short periods, so he must use to the full those glances he can give to it. Folded maps, plainly marked with the Required Track, and calibrated with a Time-Scale, are a great aid to rapid pin-pointing.

5° Lines

72. When marking the Tracks to be followed on the maps, it is a good plan to draw lines inclined at 5° intervals from the starting point and destination, as well as from any intermediate turning points. These serve to indicate after departure and before arrival the extent of the *Track Error* that may have occurred through not calculating or steering the proper Course to make good the required Track. Since a protractor cannot easily be used by the Pilot on his map, he can judge by eye from the 5° lines the angle between the Track he is making good and that which he *should* be following.

When preparing the maps in this way, the Pilot should, if possible, select suitable landmarks that will serve for pin-pointing himself in the manner described above. Such physical features as large rivers, prominent hills or valleys, lakes and coastlines are admirable and may be supplemented by any distinctly-shaped railways or roads that are likely to be recognisable while in flight.

Track Error

73. It is often most useful to remember that one mile subtends an angle of 1° at a distance of approximately 60 miles. Thus there is a close relationship between the distance the aircraft may be from the required Track and the total Track error expressed in degrees. The following Table is based upon this fact. However, it is not intended that the Pilot-Navigator should attempt to memorise its contents, though the line in heavy type should be easy to remember.

Distance Run or to be Run (Miles)	Track Error									
	Miles									
	1	2	3	4	5	6	7	8	9	10
	Degrees									
5	11	22								
6	9	18	27							
7	8	16	24	30						
8	7	14	21	27						
9	6	13	18	24	29					
10	6	11	17	22	27	31				
20	3	6	9	11	14	17	19	22	24	27
30	2	4	6	8	10	11	13	15	17	18
40	1	3	4	6	7	9	10	11	13	14
50	1	2	3	5	6	7	8	9	10	11
60	1	2	3	4	5	6	7	8	9	10
70	1	2	2	3	4	5	6	7	7	8
80	1	1	2	3	4	4	5	6	6	7
90		1	2	3	3	4	4	5	6	6
100		1	2	2	3	3	4	5	5	6

74. The application of 5° lines and of estimations of Track error is as follows :—

An aircraft is flying from A to B (Figure 3). The Pilot pin-points himself at X which he estimates by eye as 3° to starboard of the required Track.

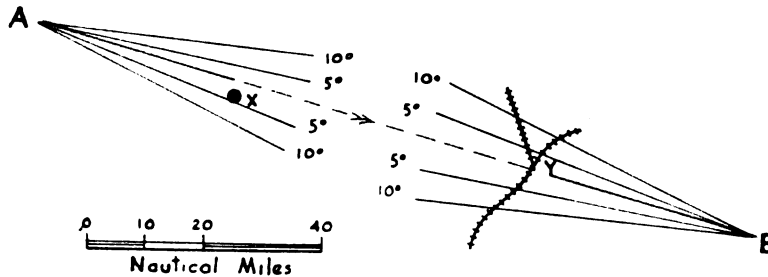


FIGURE 3. Pilot-Navigation.

If he alters Course by 3° to Port he will probably only make good a Track parallel with and to starboard of the required Track. (This is not strictly true because in so doing the direction of the Wind relative to the Course is altered, and Drift may not remain what it was before. Yet for most practical purposes the change of Drift caused by such a small alteration of Course can be neglected.)

In order to converge on to his destination, the Pilot alters Course in fact by *more* than 3° to port. How much more depends on the actual Track error and the distance still to go. The Track error is 2 miles to starboard, which corresponds approximately to 1° in the remaining 100 miles. Hence the Pilot alters Course by $(3^\circ + 1^\circ) = 4^\circ$ to Port.

Similarly when he passes over Y, he alters Course by the angle between the Track made good and the newly-required Track. This angle amounts to the sum of the angle between the original Track and the T.M.G. (about 1°) and the angle between the original Track, and the newly-required Track (about 1°). He therefore alters Course by 2° to Starboard in order to arrive at B.

Strictly speaking these last calculations should be based on 5° lines and Track error *relative to the Track from X to B*, and not to the original Track, AB. But the results are likely to be well within the accuracy of the Pilot's methods as a whole.

Summary of Pilot Navigation Procedure.—

75. The following general procedure will be found of assistance in navigating cross-country flights :—

- (i) *In the Briefing Room.*—Obtain the necessary maps. Study intended route, in conjunction with S.D. 158, S.D. 300, and Confidential Balloon Areas Map for Danger Areas, Prohibited Areas, etc., which it will be necessary to avoid. Note height of ground to be traversed. Draw tracks and 10° lines on map. The 10° lines should be drawn as broken lines, so that they are not confused with the track.
- (ii) Study the map carefully for important landmarks on and near the track. Pay particular attention to the first 25 miles of each leg.
- (iii) From the best available meteorological information, select a height to fly, bearing in mind height of cloud base, visibility, and height of ground on and near tracks.
- (iv) Take the R.A.S. for the particular type of aircraft and convert it to T.A.S. according to the height shown in the Flight Plan.
- (v) Calculate magnetic course, ground speed and time for each leg. Complete the Flight Plan on a Form 433A.
- (vi) Mark off along the track a scale at intervals of 5 or 10 minutes, flying at the calculated Ground Speed.
- (vii) *In the Aircraft before Take-off.*—Set altimeter to the height of the aerodrome.
- (viii) Consult the pilot's compass deviation card and make a note of the Compass Course for the first leg.
- (ix) Note the approximate direction of departure from the aerodrome.

(x) Consult Airspeed correction card to find the I.A.S. at which to fly to make good the R.A.S.

(xi) *In the Air*.—Climb to selected height and trim aircraft to fly hands off at a constant height and previously selected correct indicated Airspeed.

(xii) While flying on an easterly or westerly course synchronise the direction indicator with the Magnetic Compass.

(xiii) Fly to a position about 2 miles to the opposite side of the aerodrome to that of departure on track.

(xiv) Turn on to course by Direction Indicator so as to pass over the centre of the aerodrome at the selected height, air speed, and on the required course.

(xv) Note the time when exactly over the centre of the aerodrome. Calculate E.T.A. and *write it down*.

(xvi) Maintain course and Airspeed accurately until the position of the aircraft can be checked in relation to a land mark. This check should generally be made after 5 or 10 minutes flying from point of departure.

(xvii) If not on the required track, estimate and note down in degrees the Track Error.

(xviii) Alter course towards the required track by the amount of the Track Error and note this down as the "corrected course" (this course, if steered, should carry the aircraft parallel to the track required).

(xix) Therefore, to regain the track again, alter course further by an amount equal to the Track Error and note down also this alteration to the course (*see para. 74*).

(xx) On regaining the required track, steer the "corrected course" as noted down.

Note.—If a distance greater than half of the track has been flown before the Track Error can be estimated, an alteration of course should be made to regain the Track as directly as possible.

(xxi) Take every available opportunity of calculating the Ground Speed and checking E.T.A. from the time marks on the track line (*para. vi*). If the actual Ground Speed differs from that estimated, note the difference and remember that the other time marks will be proportionately out.

(xxii) Check Direction Indicator every few minutes by a quick glance at the compass when the aircraft is flying straight and level. Correct for precession whenever necessary by turning aircraft very slowly until it is on correct course by compass. Cage, reset and uncage Direction Indicator.

SPECIAL PROBLEMS OF THE NAVIGATOR

Unfavourable Weather Conditions

76. Weather conditions very largely govern the conduct of war in the air. The Navigator will often be confronted by dangerous weather conditions, and he will be more successful and more confident if he has meteorological knowledge sufficient to enable him accurately to assess the extent of any weather hazard which confronts him, and to avoid it or minimise its effects. Besides its value in showing how to avoid accidents due to weather, meteorological knowledge is also essential for taking advantage of weather conditions either to reach a target unmolested, or, if need be, to escape from the enemy. At the same time, a little knowledge is a dangerous thing, and reliable weather forecasting comes only after years of study.

The following notes on the dangerous effects of some atmospheric conditions are given only as a summary. They are not intended to replace a more detailed study of the weather as given in the Meteorological handbook for Air Crews.

(i) *Fog and Low Cloud*

These imply equally serious disabilities to the Navigator, for when flying in or above them they partially or wholly obscure the ground and prevent map-reading and observations of drift. Fog is nearly always a handicap, but low cloud away from high ground can be utilised for reaching an objective. Full details of this use of cloud are given in the Chapter on Cloud-Flying in the Meteorological handbook.

Thin fog, through which the ground immediately below can be seen, will often prevent a safe landing at an aerodrome by becoming opaque when looked through in a nearly horizontal direction.

Cloud must never be entered in the neighbourhood of and below the level of high ground, and flying really low through fog or cloud should only be done under the guidance of a Blind Approach system. It is also inadvisable to fly just in the base of low cloud. The aircraft should be either well below the cloud or high up in or above it.

(ii) *Ice Accretion*

Ice accretion is an exceedingly serious danger when it occurs at low levels. It is not of great importance in summer owing to the great height of the freezing level at that season.

In mild cases the ice may cover the aerial and render the wireless equipment useless, or may choke the carburettor or Airspeed pressure head. More serious is heavy ice accretion on the wings and airscrews. Heavy ice on the wings reduces the lift by distorting their shape, besides adding to the weight of the aircraft. Ice on the airscrews breaks off unevenly, setting up severe engine vibration, while the pieces thrown off may cause structural damage to the aircraft.

Heavy ice accretion only takes place in thick clouds or in *rain*, and when the temperature is below 0° C. It may occur with temperatures down to -12° C. or even -18° C. in cumulo-nimbus clouds. The ice then formed is of a glassy appearance and is nearly transparent. The icing called "glazed frost," which occurs when an aircraft flies in air whose temperature is below 0° C., and through which *rain* is falling, is particularly dangerous and it is advisable to turn back at once out of the rain.

The action to be taken on encountering ice in clouds depends upon the type of cloud. Full details are given in the Meteorological handbook.

As much use as possible should be made of gaps when climbing or descending through ice-forming clouds, always taking care when in the vicinity of high ground. Details of the levels and cloud types in which icing is likely to be met on a given flight are given in the route forecast.

(iii) *Bumpiness*

Any bumpiness makes observations with a bubble sextant extremely difficult. When severe, it is a great hindrance to the work of the Navigator and may be dangerous to the safety of the aircraft. Violent bumps occur in high Winds around cliffs, buildings and steep places in general. The disturbance extends up to three or four times the height of the obstacle. On lee slopes strong downward currents of air occur, and on windward slopes there are strong up-currents.

High ground, cliffs or buildings must never be approached into Wind without a reserve of height.

Bumpiness is also experienced in the vertical currents produced by convection. These are particularly severe in cumulo-nimbus clouds. Over desert areas in daytime, such bumpiness is very pronounced, although, owing to the dryness, there may be no clouds to show the existence of the ascending currents. Dust "devils" and rising flocks of birds sometimes indicate their existence, however.

Another cause of bumpiness is the eddying motion of the air produced by ground friction. This increases with the Wind strength and decreases with height. It may thus usually be avoided by climbing.

(iv) *Lightning*

Lightning is produced by large cumulo-nimbus clouds. The likelihood of an aircraft being struck is greatly increased if the trailing aerial is out, and the effects are then more severe. There is no known case of an aeroplane being wrecked by lightning, but there are numerous cases in which lightning has struck the aerial, destroyed the wireless set and burnt or shocked the Wireless Operator. Further, the blinding flash has been known to stun the Pilot for a few seconds. A secondary effect is to upset the magnetic compass, and after flying through a thunderstorm it is as well to make a routine check of the Course by astro-compass. Besides the shape of the clouds, warning of lightning is given by heavy atmospherics in wireless reception, and by sparks and "flames" on metal parts of the machine. When it is clear that the aircraft is approaching an electrical storm, it is essential to "earth" and then to wind in the aerial. Apart from their lightning, thunder clouds are exceedingly bumpy, and it is as well to avoid them.

Choice of Route

77. The Navigator will often have to decide what route to follow on a flight. The choice is generally one between the most direct Track and a longer one that for various reasons may be preferable.

It has been explained that following a great circle Track is very often more bother than the saving in distance and time over the rhumb line Track is worth. On a flight the length of a transatlantic crossing, the great circle Track may, however, be the more acceptable.

A special reason may sometimes be the deciding factor. For example, the change of Variation between one place and another may exactly correspond with the convergency between their respective meridians. That is to say the magnetic direction of the great circle between them may be constant. By making good this *Constant Magnetic Track*, the aircraft will in fact follow the great circle arc between the two places, without the trouble of re-setting the Course for changes in the True direction of the great circle arc. Such opportunities are purely fortuitous, an example being a flight East or West in 1941 between Iceland and Greenland.

78. Diversions from the most direct Track or from the rhumb line track are often advisable for one or more of the following reasons :—

(i) *To make sure of a pin-point* near an obscure destination. The latter may be very difficult to recognise from the air, and the best plan is to route the aircraft *via* the nearest prominent and unmistakable land- or sea-mark, whence the flight to the destination will be short and certain.

(ii) *To avoid enemy-defended areas.* In war certain areas known for their anti-aircraft defences may be avoided by routing aircraft around them. Such areas include balloon barrages, gun defences and searchlights.

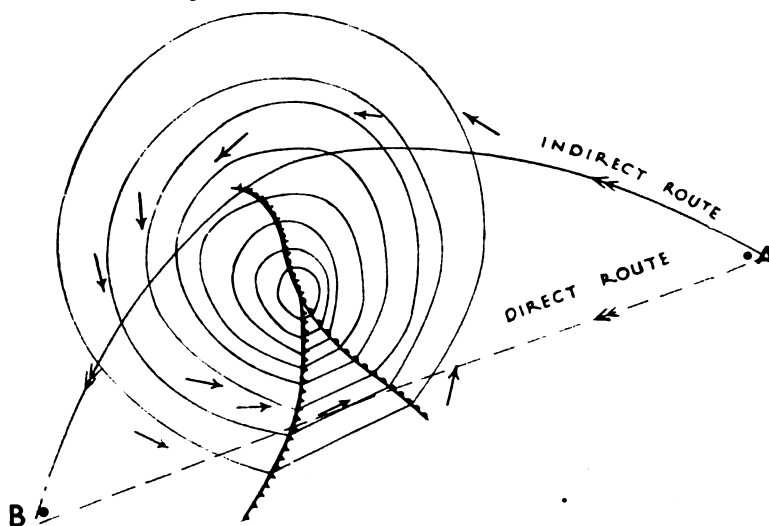


FIGURE 4. Route Avoiding Unfavourable Weather.

(iii) *To avoid unfavourable weather.* Contrary Winds, "fronts" and localised storms can often be avoided by an astute choice of route, especially on long flights. In extreme cases it may be profitable to choose the long way round a depression to obtain favourable Winds, rather than taking a short cut on which contrary Winds are to be expected. (See Figure 4.)

(iv) *To avoid difficult country.* Flights by single-engined land planes over the open sea, by flying boats and float planes over wide land areas, or by any type over impenetrable forests and inaccessible deserts are sometimes best avoided altogether by taking a longer but less hazardous route. Besides avoiding unnecessary danger, a Navigator can often actually save time when, for example, a high mountain lies on the direct Track, by flying round rather than climbing over it.

(v) *To conform to the restrictions laid down in S.D. 158.*

Procedure When Lost

79. When a destination, target or rendezvous cannot be found at the E.T.A., there are several courses open to the Navigator: broadly speaking he can either look at random, or he can adopt a systematic search. It scarcely need be said that the former action almost invariably leads into worse difficulties, and would never be adopted if Navigators and/or Pilots were not prone to rely on their instincts in emergency, when cold reason alone will save the situation.

When "lost" it is imperative not to add to the troubles by *vague "circling."* This is one of the quickest ways of confusing the ablest Navigator, since the Courses cannot be plotted and because the aircraft is carried down-wind an indeterminable distance. The chances of map-reading under difficult

conditions are greatly reduced if the approximate position of the aircraft cannot be calculated. Thus every minute spent "circling" is almost always wasted unless some point can be seen around which to circle.

The "lost" condition is frequently due to errors in plotting and in D.R. Navigation, and the first action of the Navigator should not be to blame faulty instruments, but to check carefully over his plotting with the aid of his log. While he is doing this, the aircraft should continue on its Course, unless the Navigator has provided against a possible emergency and drawn up the details of a square search, or other plan of action.

The square search is the easiest system to adopt at a moment's notice. It is fully described in Chapter X, paragraph 4. It relies for success on the Navigator's being able to see the objective sought from a reasonable distance, a condition not always experienced at night, for example.

It is not possible to lay down hard and fast rules for every case. It has often been found in practice that a carefully observed astro fix affords a satisfactory answer in the difficult circumstances when communication with the ground is not possible.

When homing in the British Isles, Flying Control provides invaluable assistance to aircraft in distress. The functioning of this organisation is briefly described in Chapter XI, paragraph 12.

When the W/T has broken down, the Air Navigator, unequipped for astro observations and flying by night has recourse to several aids to navigation. Amongst these are—

Coastal Lighthouses

Aerial Lighthouses

Landmark Beacons

and a system of co-operation with the searchlights.

The procedure to be adopted for the illumination of these lights, and the complete schemes as to their disposition, cannot for reasons of security be published in this Manual, but may be found in the appropriate Air Ministry Confidential Orders and Command Operational Instructions.

Above all do not descend below cloud **unless absolutely sure there is no high ground nearby.**

Common Causes of Error in Navigation

80. It may be cold comfort to the student to learn that the most common cause of error in Navigation is lack of experience, yet such is the case. It is difficult for a beginner to know exactly what to do in the air, distracted as he is by the many novel and fascinating sights and sensations of flying. Furthermore, he will not be accustomed to working in noise, cold and in a reduced oxygen supply. He will have little sense of proportion and practically no sense of responsibility, until he discovers that the success of a flight depends upon *his* making careful preparations on the ground, and upon *his* keen observations in the air. He will probably learn most from his failures, if he is honest with himself and is willing to admit mistakes, which are bound to occur. Above all he must never consider himself beyond acquiring further knowledge; for the best Navigators always concede that the success of their most spectacular flights was, to some extent at least, due to that undefinable element which, for want of a better name, is called "luck." The unexpected is always happening, and it gives zest to the Navigator's duties. The Navigator must always be on his guard against the following sources of error :—

(i) *Slackening vigilance.*—When everything seems to be going according to plan, or because of growing fatigue, the Navigator may relax his attention and lose an important but fleeting opportunity of checking his Navigation. After a long night flight, when it is important to pin-point the aircraft, say, as it crosses a coast-line near its destination, the Navigator may not keep a look-out early or long enough and so may miss seeing the coast-line altogether.

(ii) *Jumping to conclusions.*—This happens often, and results from wishful thinking. A prominent ground object that has been anxiously anticipated may, in the heat of the moment, be confused with something similar that comes into view. A good Navigator develops a coldly methodical outlook and a passion for objective observation.

(iii) *Mental calculations.*—It is highly desirable for the Navigator to keep his wits about him and to check his calculations mentally. For example, he should reason that because Variation is, say, Westerly, Magnetic directions must be *greater* than True directions. Exactly *how much* greater they are, should be decided with pencil and paper, because mathematical ability is one of the first faculties of the Air Navigator to suffer in flight. Even the simplest mathematical work should be laid out in the log. This weakness should never be forgotten and good Navigators spare no trouble in checking over their calculations again and again.

(iv) *Using the wrong Wind.*—This is at the bottom of many navigational failures. A frequent check of Wind Velocity is of immense practical value, especially when at a great height where

Wind Speeds are often very high. There is a common tendency to use a Wind found retrospectively (e.g., a *mean* Wind found, say, by Air Plot). This practice has serious limitations since the Wind thus found probably bears little relationship with the Wind to be encountered ahead. A careful and intelligent study of the pressure distribution on the weather map before flight will enable an expert practical Navigator to estimate the probable Wind ahead from his own observations of the Wind so far experienced. Ability to assess probable Winds is part of his *Sixth sense*, already alluded to in this Manual, and is largely learnt by experience.

(v) *Badly calibrated instruments.*—If the watch, compass, airspeed indicator, altimeter, loop and sextant are not functioning properly or are registering incorrectly, accurate Navigation is impossible. * Errors that arise from one source alone are sometimes sufficient to cause navigational failure.

(vi) *Failure to compute True Airspeed.*—This results in incorrect plotting and wind-finding. It must be remembered that a properly calibrated Airspeed indicator is still subject to Position Error, and to changes of air density. Height must consequently be allowed for ; and the practice of adding 1.75 per cent. of the Corrected Airspeed per Thousand Feet works with reasonable accuracy, if a Height and Airspeed Computer is not available.

(vii) *Incorrect Time-Keeping.*—Unless the Navigator synchronises the watches of the Pilot and W/T operator, there invariably arises confusion over Times to alter Course, E.T.A.s, and Times of D/F observations. Slackness in recording times of observations of all kinds may cause sensible errors in plotting, wind-finding, or in the D.R. Navigation.

(viii) *Applying Wrong Deviation and Variation.*—This is a familiar pitfall. It must be remembered that Deviation is the correction to apply to Compass directions to obtain the equivalent Magnetic directions ; while Variation is the correction to apply to Magnetic directions to obtain the equivalent True directions. Moreover, Deviation depends upon the magnetic Course, a fact that is often overlooked when taking *bearings* with a magnetic compass.

(ix) *Setting Reverse or Incorrect Courses.*—This is a very popular cause of navigational failure, due entirely to carelessness. The Navigator must keep a wary eye on the Course actually steered by the Pilot, who, for various reasons, may not be steering the requisite Course. A check is best made by referring to the Course-checking compass when provided. Otherwise it is advisable to look repeatedly over the Pilot's shoulder at the Course being steered.

(x) *Overshooting the Base.*—When homing by D/F in bad weather, the aircraft will sometimes pass right over the station without the Navigator realising the significance of the sudden change of bearings.

(xi) *Neglecting all available checks.*—When engaged on certain tactical duties, individual activity is often very limited in scope. Nevertheless, all possible checks should be used to verify the T.M.G., the G/S, E.T.A.s, and W/V. For example, on an interception of a Convoy, it is insufficient to set Course and wait for the E.T.I. It is advisable to maintain the Track to intercept, determine the G/S and calculate which way to turn along the Convoy's Track if nothing is sighted at the G.P.I.

(xii) *Relying too much on D/F.*—D/F is intended to be only an AID to Navigation, yet it is a common mistake to consider D/F facilities as an easy *alternative* to Navigation. When conditions favour good reception and in the absence of enemy interference or signals congestion, D/F provides very useful details concerning position, Track, Courses to steer, and drift. But there must be a framework of D.R. Navigation on which to fit this information. It is very difficult to revert to D.R. Navigation if the W/T breaks down, after having been employed for a large part of any flight, to the exclusion of other navigational observations. D/F facilities themselves may cease without warning in war time.

(xiii) *Lack of preparation.*—From the extreme case of going into the air without a clear idea of the duty to be performed or the route to be followed, to the case where, say, the message pad is left behind, stretches a vast array of oversights and omissions that are likely to occur if ample time and effort are not devoted to preparing for a flight. Trivial though the consequences may be in the latter case, the Navigator will often find himself inconvenienced, if not seriously embarrassed, by not having all the necessary maps, instruments, publications and information for a flight.

(xiv) *Inactivity.*—Flying induces a form of inertia that strongly resembles laziness. Whether that stigma is deserved or not by any particular Navigator, as a general rule there is a very strong inclination to be inactive during flight. This results in a dearth of all kinds of observations, even the simplest of all, drift, going unchecked far too long on many occasions. Symptoms of

inertia are found in a poorly-kept log, in failure to check Wind regularly, or to practice astronomical observations on occasions when these might have been taken if only for the sake of keeping adept. Generalisations in respect of the amount of activity required of the Navigator are of little value, since the character of each individual flight has to be considered. It can however be stated that, while confusion and fatigue might conceivably be caused by over-activity, errors in Navigation arise much more frequently from wrong assumptions being made on account of inactivity.

(xv) *Failure to warn the Pilot.*—When taking D/F loop bearings, back-bearings with the rear gun, or drift readings, and when using a bubble sextant or an astro-compass, accurate results are only obtainable when the aircraft is flown carefully. It is the duty of the Pilot to keep a steady Airspeed and Course (particularly the latter) when warned that the Navigator is about to make the above observations. The Navigator should not hesitate to warn the Pilot, on these occasions, and, of course, must say when he has finished so that the Pilot can relax.

PRACTICAL SOLUTION OF VELOCITY PROBLEMS.

Navigation Computer Mk. III

81. This is a semi-mechanical device for plotting the velocity problems of Air Navigation. It is made in three types. Mks. III, C and D can be secured to the thigh and are designed for use by Pilots when seated. They carry a pencil and a small note-pad under a flap, on the back of which is set a circular slide rule and a Height and Airspeed Computer for instruments calibrated isothermally* (C) or according to the I.C.A.N. convention* (D).

Mk. III F is for use by Navigators, and apart from not having straps, a flap or a note-pad, it is virtually the same as the other types.

Principle of the Computer

82. The Computer reproduces within a rotatable compass rose that part of the normal triangle of velocities with which the Air Navigator is primarily concerned; namely, it shows the Wind vector applied between the vector of the Course and True Airspeed, and the vector of the Track and Ground Speed.

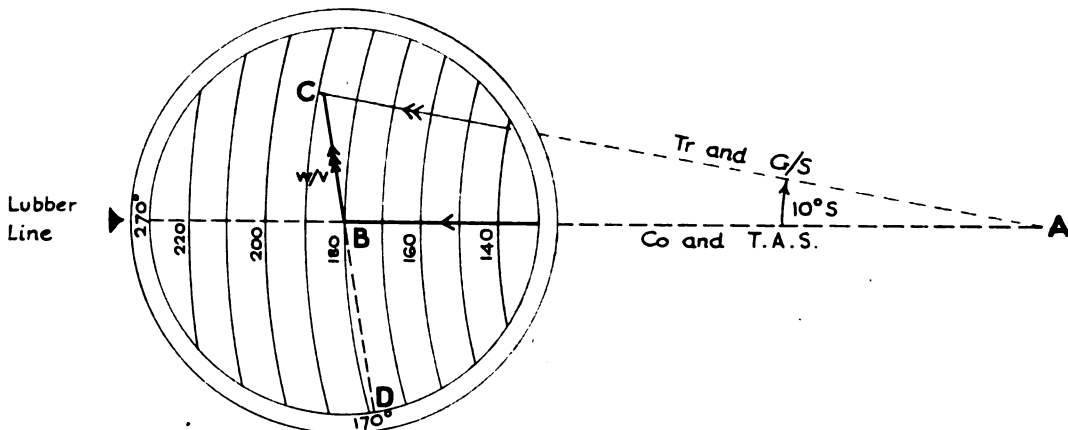


FIGURE 5. Principle of the Navigational Computer, Mk. III.

This is shown diagrammatically in Figure 5, in which ABC is the conventional vector triangle.

The direction of AB, the Course, is determined by orienting the compass rose to register the required direction, say 270° T, against a lubber line (called "True Course" on the Computer).

In so doing, the other two vectors are oriented relative to the compass rose. Thus, the Wind vector, BC, is laid off *down-wind* from B. The Wind Direction is, therefore, from D, namely 170° T in Figure 5.

Similarly, the direction of the Track is so many degrees to port or starboard of the Course. In Figure 5 the drift is shown as 10° S. Hence the Track is $(270^\circ \text{ T} + 10^\circ) = 280^\circ \text{ T}$.

The lengths of the vectors are drawn to a fixed scale. This scale is marked on an endless band as a series of concentric arcs drawn from centre A at varying speed-intervals. There is also on the endless band a small square-ruled section, the use of which will be explained later.

* See Glossary.

Thus if AB in Figure 5 is 180 k, AC will be 188 k and BC 36 k.

Because it is unnecessary to have more of the vector triangle than is contained within the compass rose, the dotted portions of AB and AC are not visible on the Computer. Instead, the endless band can be turned past the centre of the compass rose, extending AB (and consequently AC) in length for True Airspeeds ranging from 40 to 440 k or m.p.h.

The compass rose contains a translucent window which acts as a *plotting dial*. The vectors can be drawn and appropriately labelled upon its matt surface. At its centre is a *dot* which serves as a datum point (usually the extremity of the Course vector).

The orientation of the plotting dial should normally be in True directions, in conformity with recognised navigational practice. However, if required, a Variation scale is provided by which True directions may be converted visually to Magnetic and *vice versa*. The Variation scale may be similarly used if required for applying drift visually to the Course to obtain the Track and *vice versa*.

83. A few typical uses will now be demonstrated. Always remember that on the Computer, the Wind blows OUTWARDS from the dial dot.

(i) To find Track and Ground Speed. (See Figure 6.)

Given :	Co.	185° T.
	T.A.S.	240 k.
	W/V	105°/33 k.

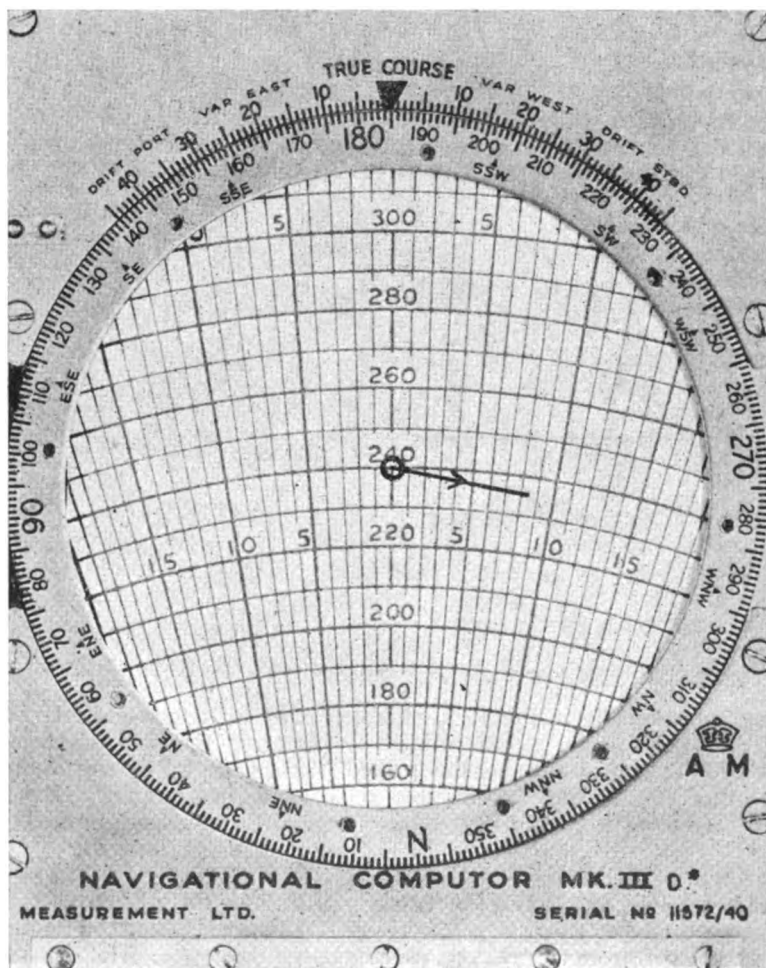


FIGURE 6. To Find Track and Ground Speed.

(a) Set the W/V. To do this, rotate the dial until 105° registers against the lubber line ("True Course") and draw a line from the dot away from the direction set, equal in length to 33 k on the scale. Put an arrow on this Wind vector.

(b) Set the Co. and T.A.S. To do this, rotate the dial until 185° registers against the lubber line ("True Course"). Then turn the endless band until 240 k lies exactly under the dot.

(c) Read the answer off against the outer extremity of the Wind vector. That is, the drift is seen to be 8° S, from which the Track can be deduced from the Course mentally ($185^\circ \text{ T} + 8^\circ = 193^\circ \text{ T}$) or read off on the dial against 8° S on the Drift Scale. The Ground Speed is seen from the concentric arcs to be 236 k.

(ii) To find Course and Ground Speed. (See Figure 7.)

Given : Tr. Required 300° T .
 T.A.S. 320 k.
 W/V $195^\circ/45 \text{ k}$.

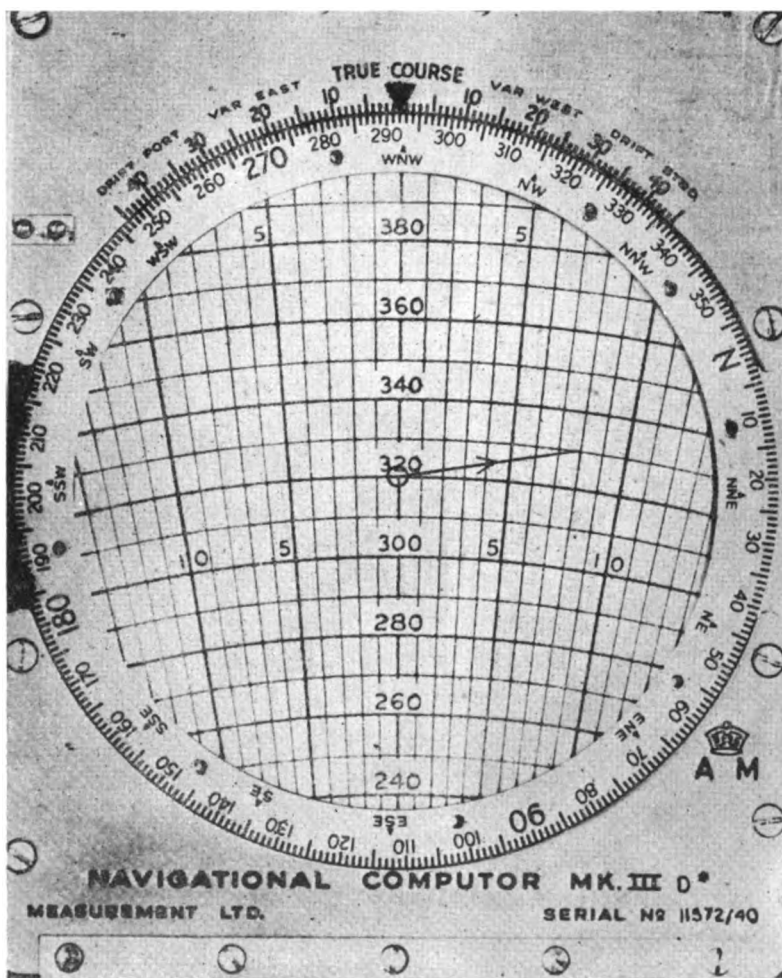


FIGURE 7. To Find Course and Ground Speed.

(a) Set the W/V as in (i) (a) above.

(b) Set T.A.S. as explained in (i) (b) above.

(c) Rotate the dial until the required Track (marked in pencil on it) is registered against the lubber line ("True Course"). Read the drift registered at the extremity of the Wind vector that would be experienced if a Course of 300° T were steered. This is found to be $7\frac{1}{2}^\circ$ S.

(d) Set the required Track mark on the dial against the Drift Scale, at the drift found at (ii) (c) above.

(e) Adjust the dial slightly to make the drift registered on the Drift Scale against the required Track mark, agree exactly with the drift registered at the outer extremity of the Wind vector, i.e., 8° S.

(f) Read the Course on the dial against the lubber line ("True Course"). This is 292° T. Read the Ground Speed on the concentric arcs against the outer end of the Wind vector, 330 k.

(iii) To find W/V by Track and Ground Speed method. (See Figure 8.)

Given : Co.	095° T.
T.A.S.	230 k.
T.M.G.	085° T.
G/S	245 k.

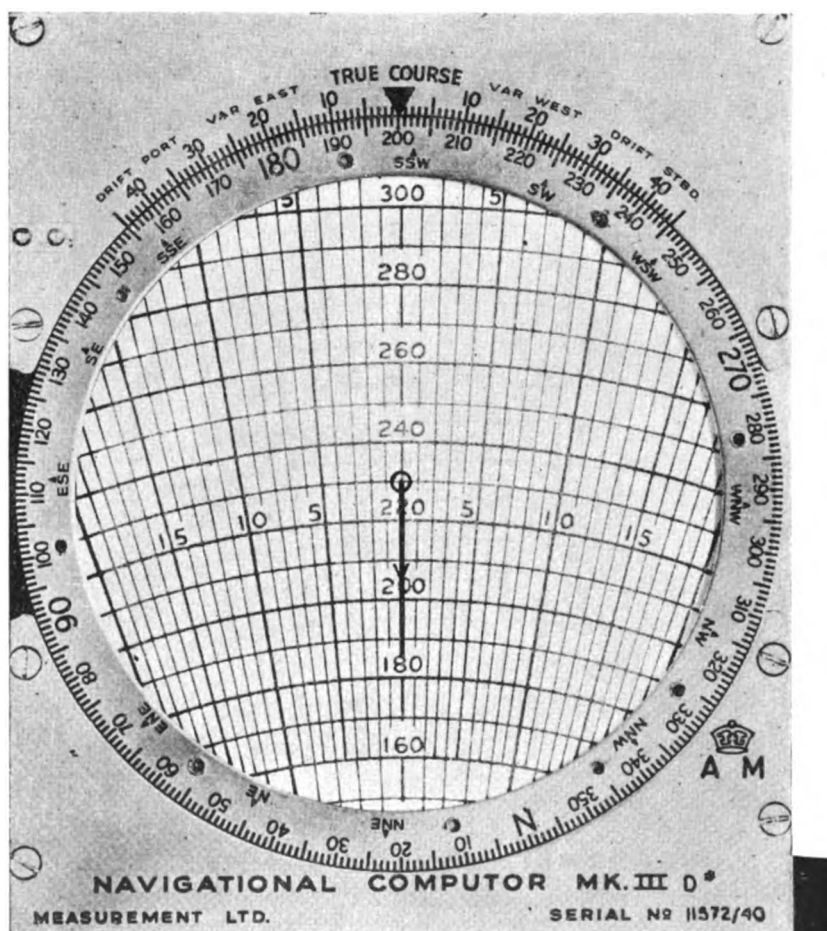


FIGURE 8. W/V by Track and Ground Speed Method.

(a) Set the Co. and T.A.S. as described in (i) (b) above.

(b) Set the T.M.G. and G/S. To do this, deduce the drift either mentally ($095^\circ - 085^\circ = 10^\circ$ P. or with the aid of the Drift Scale. Mark a point in pencil on the dial where the line of 10° P drift registers with the concentric arc of 245 k.

(c) Draw a line from the dot to this point. This is the Wind vector. To measure it, rotate the dial until the vector is exactly aligned with the lubber line, but lies on the opposite side of the dot. Read off the Wind Direction against the lubber line, 200° T. The Wind Speed is read off from the concentric arcs and found to be 45 k.

(iv) To find W/V by Multiple Drifts. (See Figure 9.)

Given :	T.A.S. ...	230 k.
	Co. 195° T ...	drift 7° S ;
	Co. 257° T ...	drift 6° S ;
	Co. 332° T ...	drift 2° P.

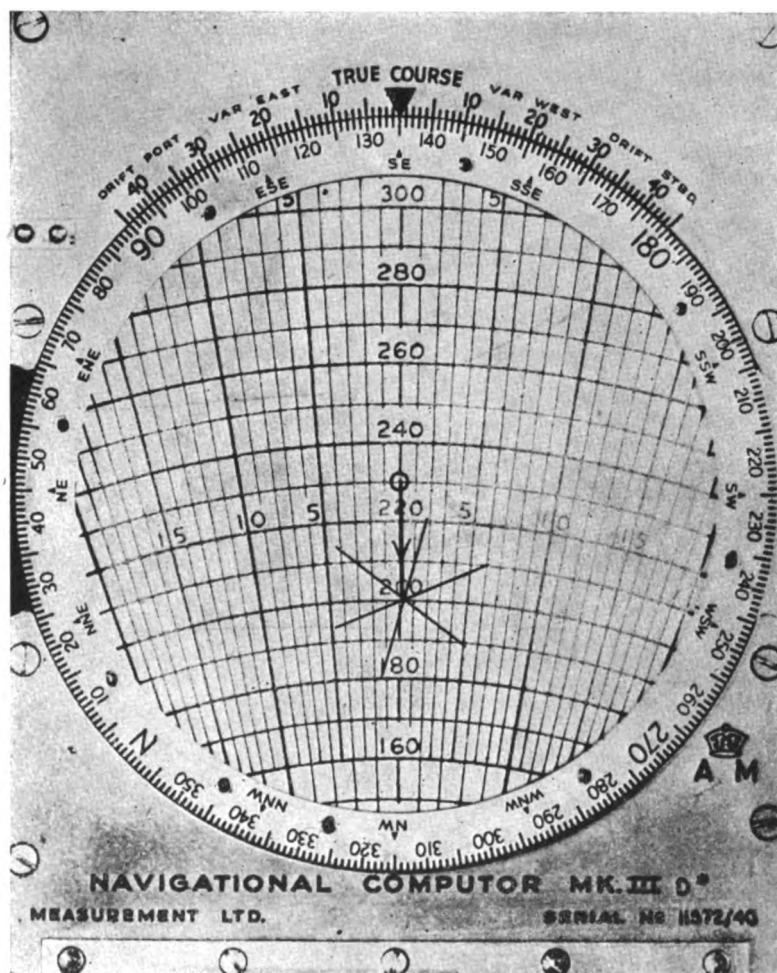


FIGURE 9. W/V by Multiple Drifts.

- Set the T.A.S. as explained in (i) (b) above.
- Set each Co. in turn against the lubber line ("True Course").
- As each Co. is registered, draw in pencil a short line along the drift line appropriate to that Co.
- The drift lines intersect at a point, or more commonly at a "cocked hat." Draw a line from the dot to this point or centre of the "cocked hat." This is the Wind vector which is measured as described in (iii) (c) above, and found to be $135^{\circ}/30$ k.

(v) *Keeping an Air Pilot.* (See Figure 10.)

Given :- T.A.S.	240 k.
W/V	320°/30 k.
1st Co.	300° T for 6 minutes.
2nd Co.	010° T for 4 minutes.
3rd Co.	050° T.

What is the Track and distance to return to the starting point after 10 minutes on the last Co. ?

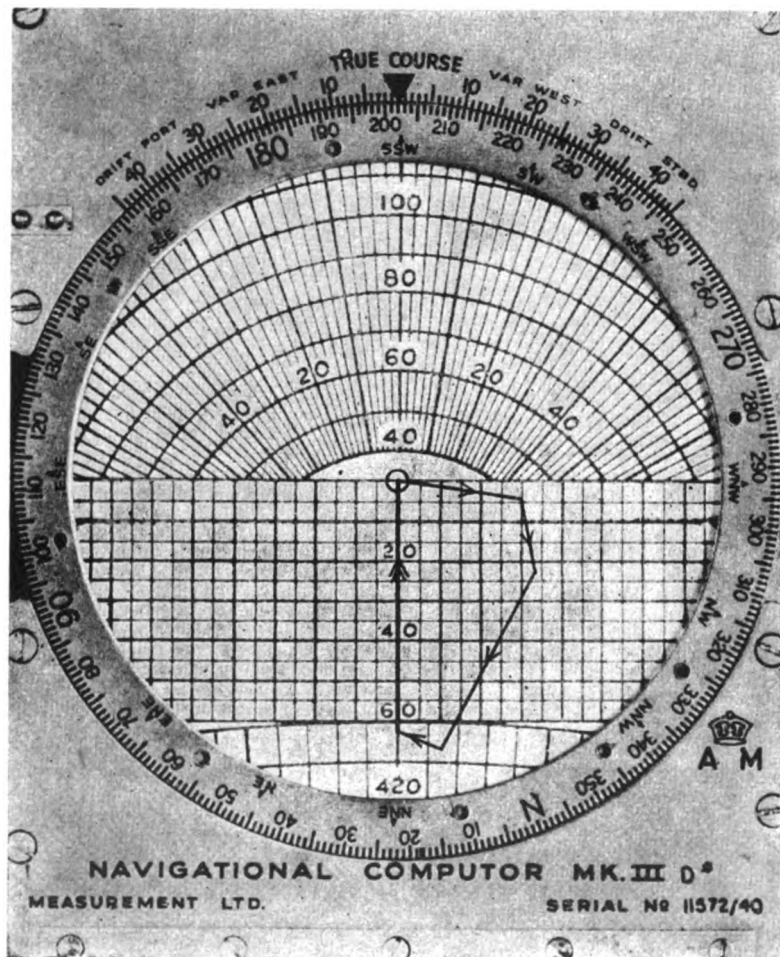


FIGURE 10. Keeping an Air Plot.

(a) Turn the endless band until the square-ruled section is under the dial.

(b) Set the first Co. against the lubber line ("True Course") and from the dot draw a line TOWARDS the direction registered, and equal to the air distance flown in 6 minutes. This is found (by using the circular slide rule on the Computer) to be 24 n.m. An arbitrary scale of 1 square to 4 n.m. or other suitable number is then chosen.

(c) Repeat for the second and subsequent Courses, drawing a line of correct length to scale and parallel to the sides of the squares from the end of the first or subsequent Courses.

(d) Lay off the Wind effect for the total time of flight. This is found (by using the circular slide rule) to be 10 n.m. in 20 minutes. Turn the dial to register 320° T against the lubber line ("True

Course") and from the end of the last Co. plotted, draw a line parallel to the sides of the squares but **AWAY** from the lubber line. The end of this line is the *D.R. position* after 20 minutes flight.

(e) Turn the dial until the *D.R. position* is aligned with, but on the opposite side of the dot to the **lubber line** ("True Course"). Read the direction of the required Track against the latter, namely **202° T**. Read the distance from the *D.R. position* to the dot as so many squares. These are found to number 12½, equivalent to 50 n.m. at the chosen scale.

(vi) *Correcting the W/V by Finding the Error in a D.R. Position.* (See Figure 11.)

Given : W/V used 345°/30 k.

After 20 minutes flight, the aircraft is found to be 5 n.m. distant on a bearing of 220° T from the *D.R. position*.

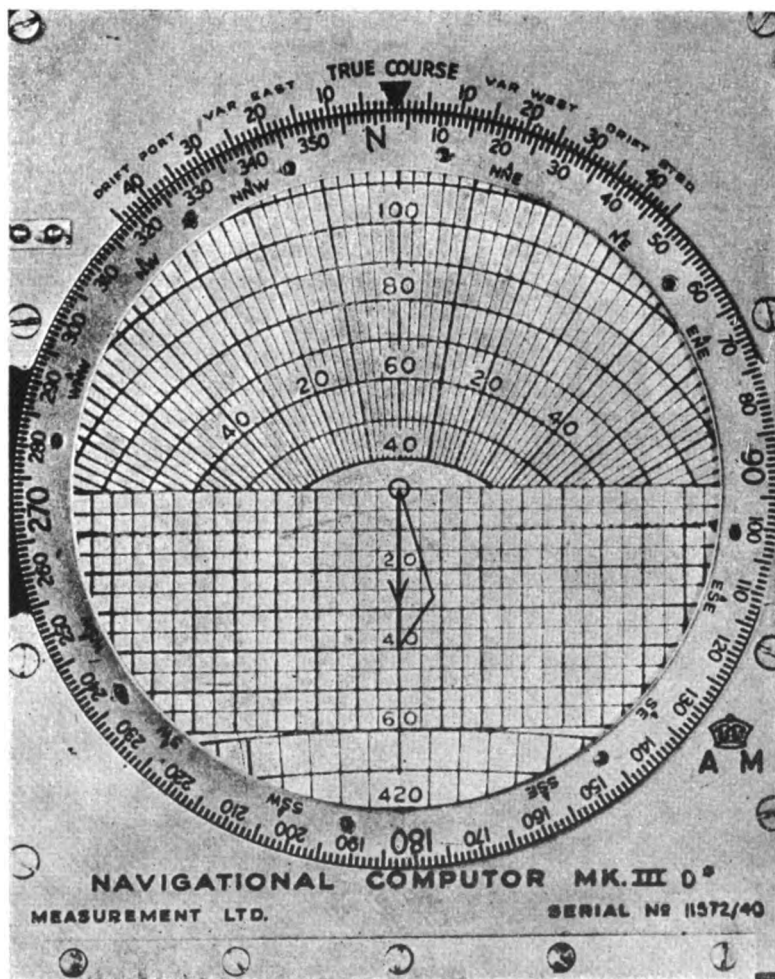


FIGURE 11. Correcting a W/V.

- Turn the endless band until the square-ruled section is under the dial.
- Set the W/V used on the dial, choosing any suitable scale. (e.g., 1 square = 5 n.m.)
- Lay off a Correcting vector from the outer extremity of the Wind vector in the direction the pin-point lies from the *D.R. position*. To do this, first calculate the error *per hour*, i.e., 15 n.m. Then

turn the dial to register 220° T against the lubber line, and draw a line parallel to the sides of the squares from the wind vector TOWARDS the lubber line. This is the Correcting vector.

(d) The line from the dot to the end of the Correcting vector is the Wind vector, $003^\circ/40$ k.

(vii) *Interception*

Interception problems that do not involve two aircraft can be solved satisfactorily on the Computer. It is best to deal with the problem in two steps by

(a) Finding the relative W/V ; and

(b) Finding the Co. and relative G/S to make good the relative Tr (i.e., the speed of closing along the line of constant bearing).

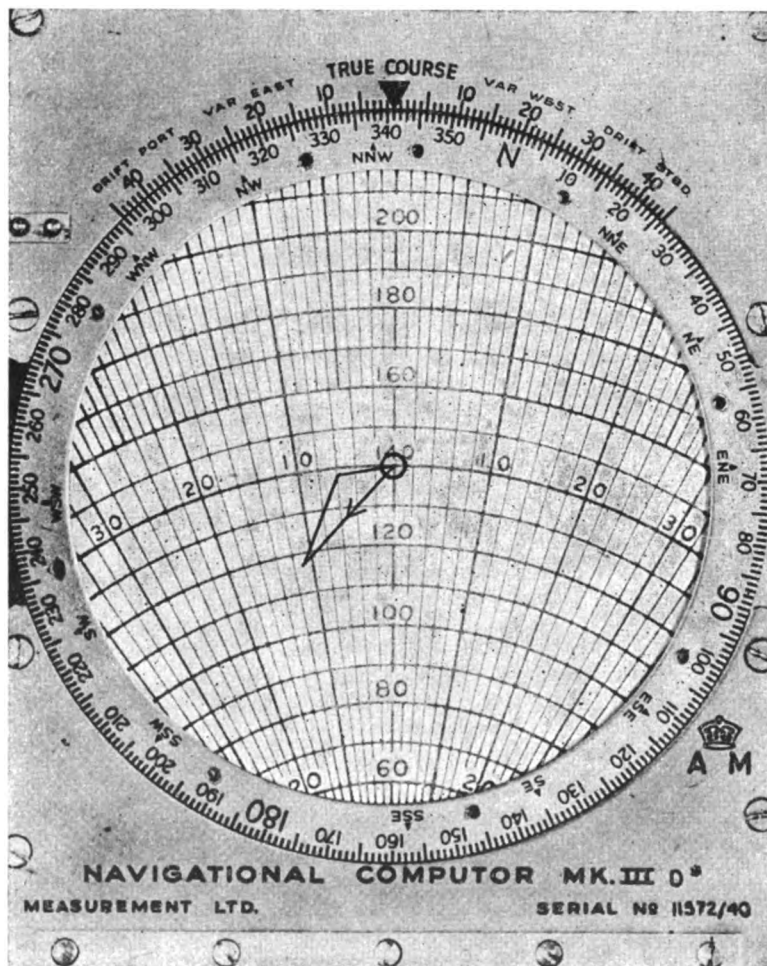


FIGURE 12. Intercepting a Ship.

Example :—To intercept a ship. (See Figure 12.)

Given : W/V $060^\circ/15$ k.
 T.A.S. 140 k.
 Ship's Tr. 000° T.
 Ship's G/S 25 k.
 Ship's position 330° T, 80 n.m. from the aircraft.

(a) The relative W/V

Set the W/V on the Computer as described in (vi) (b) above. Turn the dial until 000° T registers against the lubber line ("True Course"). From the end of the Wind vector, draw a line 25 k to scale, parallel with the sides of the squares, but AWAY from the lubber line. This is the vector of the Ship's reversed Tr. and G/S. Join the dot to the end of this second vector to obtain the vector of the relative W/V, which measures $002^\circ/35$ k.

(b) The Course and Speed to Intercept

Proceed as in (ii) above, to find the Co. to steer and G/S to make good a Track of 330° T in a W/V of $022^\circ/35$ k, with a T.A.S. of 140 k.

The Co. is found to be 341° T.

The G/S is 117 k. This is in reality the relative speed of closing along the relative Track or line of constant bearing. Hence the ship will be intercepted after 41 minutes' flight (calculated with the aid of the circular slide rule).

Note.—If, as in Figure 12, the relative W/V is found, using the same basic scale as represented by the concentric arcs, there is no need to measure the relative W/V, but step (b) can be taken immediately the first two vectors of step (a) are drawn.

Example of Practical Air Navigation

84. A navigator under training, Pilot Officer Shawbury, is detailed to make a day navigational cross-country flight over the route:—BASE—RHYL—MULL OF GALWAY—BARDSEY ISLAND—STRUMBLE HEAD—BASE.

He is briefed to carry out the exercise at 5,000 ft. on the first, second and fifth legs and at 2,000 ft. over the sea on the third and fourth legs.

85. He draws in the required tracks on his chart (blue lines on Appendix 2) and prepares his flight plan, on Form 441 (Appendix 1) based upon the meteorological forecast for the areas to be covered during the flight. He also prepares the two $\frac{1}{2}$ million topographical maps (sheets 4 and 5) and notes the spot heights along the route.

86. He checks all his navigation instruments for serviceability prior to take-off, and ensures that the following equipment is stowed in the aircraft:—

- 2 sharp pencils and a sharpener.
- 1 rubber.
- 1 navigational computer Mark III.
- 1 pair of mathematical dividers.
- 1 straight edge.
- 1 Douglas protractor.
- Air Almanac, current date.
- A.N. tables, Volume L.
- Bubble sextant.
- 3 copies F.441 and cover.
- Chart table plotter.
- Plotting map G.S.G.S. 4080 (Sheet N.W. 48/13).
- Air Maps, Topographical $\frac{1}{2}$ million, Sheets 4 and 5.
- Astro Compass.
- Message pads.
- Watch, set to G.M.T.

87. The navigator synchronises all the aircraft clocks with his astro watch (G.M.T.) and sets the altimeters to read the height of BASE airfield above M.S.L.

88. At 10.05 hours the aircraft leaves the ground and the pilot agrees to set course over base at 5,000 ft. and circles the airfield whilst climbing to this height. At 10.08 hours the navigator gives the pilot a message slip for the first course to steer (BASE—RHYL 340° C.).

89. At 10.15 hours the aircraft tracks over the centre of the airfield at 5,000 ft. on the compass course and the pilot informs the navigator "On course . . . Now!" The navigator immediately calculates the D.R. time for the length of the first leg and reports "E.T.A. RHYL 11.11 hours."

90. A drift taken at 10.19 hours indicates that the aircraft is drifting too far to port, this fact is confirmed by pin points obtained at 10.21 and 10.27 hours giving a track made good of 319° T.

91. The navigator calculates the wind velocity by track and ground speed method, checks the results by air plot, and plots ahead of the aircraft to a D.R. position at 10.30 hours, using the new ground speed.

92. From this D.R. position $52^{\circ} 00' N 01^{\circ} 54' W$ he lays in the required track to reach RHYL, using the wind found, and revises the E.T.A. RHYL for the new ground speed.

93. At 10.30 hours the new course (345° C) is set for RHYL and there is just time to obtain one drift before cloud appears at 3,000 ft. and obscures the ground. At 10.31 the W/Op. is requested to obtain loop bearings from Base to check the track made good, and from Station "X" on the beam to check the ground speed. The two bearings received at 10.34 and 10.37½ hours are combined to produce a loop fix at 10.37½ hours, from which an air plot wind is obtained.

94. The navigator decides against altering course on the loop fix, although he knows that the aircraft still to be port of track. At 10.44½ hours the aircraft's position is observed to be $52^{\circ} 25' N 02^{\circ} 35' W$ through a cloud break, and an air plot wind velocity is calculated.

95. The navigator again plots ahead of the aircraft to a D.R. position at 10.48½ hours, laying in the new required track from this point to RHYL, calculates the course to steer, and computes a new E.T.A. for the destination. The navigator passes a written course (356° C) to the pilot, who alters course at 10.48½ hours.

96. The air plot is maintained and at 11.01½ hours LLANGOLLEN is pin pointed, this confirms that the required track has been made good and the E.T.A. RHYL will be 11.12 hours and indicates that the wind is strengthening slightly.

97. Working ahead, the navigator completes the air plot to 11.12 hours, and using a wind velocity of $022^{\circ}/38$ k, he gives the pilot the next course to steer from RHYL to the MULL OF GALLOWAY.

98. At RHYL the air plot is re-started and the navigator decides to find wind velocity by the three course or multiple drift method over the sea. He gives the pilot a message slip marked with three computed courses to steer, together with the times to turn, allowing a three-minute run on each leg. Drift is observed on each course and the wind velocity determined, the aircraft resumes the original course at 11.24 hours. The navigator plots ahead for 6 minutes and establishes the air position of the aircraft at 11.30 hours, from this point he lays off 18 minutes wind effect ($014^{\circ}/26$ k) and thereby finds his D.R. position for 11.30 hours.

99. From this D.R. position he measures the new required track for MULL OF GALLOWAY and calculates the course to steer, using the new wind.

100. The landfall on the ISLE OF MAN is made at 11.41½ hours, in position $54^{\circ} 14' N 04^{\circ} 23' W$, where a timed run is commenced to check the ground speed between the two coast lines of the island. This is found to be 147 k.

101. Over the sea, height is gradually reduced and air speed increased, and the navigator adjusts the E.T.A. accordingly. At 11.50 hours the aircraft is levelled out at 2,000 ft. and a drift of 7° port is recorded before the aircraft is turned southwards towards BARDSEY ISLE at 11.52 hours.

102. The air plot is discontinued at this point as the wind is practically on the tail of the aircraft. After taking a drift on the new heading, wind velocity is checked by double drift method. The aircraft passes over the southerly tip of the ISLE OF MAN at 12.04 hours, providing an opportunity for checking the wind velocity by track and ground speed method. An alteration of course for BARDSEY ISLAND is made at 12.10 hours from a pre-plotted D.R. position, using the new wind.

A fix is obtained at 12.20 hours by combining an astro compass bearing of SKERRIES LIGHT with a transit bearing of SOUTH STACK and HOLYHEAD LTS. This confirms that the track has been made good and enables the navigator to check the ground speed.

103. BARDSEY ISLAND is reached at 12.31 hours, when course is set for STRUMBLE HEAD and the air plot re-started. A back bearing of BARDSEY LIGHT is taken and the position line obtained is compared with a drift taken immediately after the aircraft has settled down after climbing to 5,000 ft., and confirms that the T.M.G. is 188° T. A sun shot produces a position line which, with a loop bearing taken at the same time, cross the T.M.G. to provide a fix at 12.43 hours. A mean wind velocity during the climb is deduced from the fix, but time is too short for the navigator to calculate a new course to STRUMBLE HEAD. He therefore decides to run on to the coast and set course for BASE from the D.R. landfall, which he calculates to be FISHGUARD LIGHT.

104. The aircraft turns over FISHGUARD HARBOUR at 12.46½ hours at 5,000 ft. and a mean air plot wind is used to set course for BASE.

105. Drift (6° "S") is taken on the homeward leg, which is confirmed by pin pointing the town of LLANDILO at 12.58½ hours. From this position the wind velocity is assessed by the track and ground speed method.

106. Although the high cloud has dispersed, low cloud again obscures the ground and the navigator prepares to take a run of sun sights. He requests the pilot to concentrate on accurate instrument flying during the runs and asks the W/Op. to obtain D.F. bearings from Station "Y." The clear sky overhead also enables him to check the course by astro compass.

107. The sun position line plotted at 13.12.00 hours places the aircraft south of track. This line is crossed by a transferred position line from Station "Y" taken at 13.08½ hours. This gives an astro/loop fix at 13.12.00 hours, from which the air plot wind is calculated. The D.R. position of the aircraft is again plotted ahead to 13.18 hours, where the new wind is applied to the required track to give a course from the D.R. position to BASE.

108. BASE is reached ½ minute before E.T.A. and the final wind velocity is calculated by air plot method before the pilot commences to descend for landing. This wind vector has not been plotted on the chart as it may confuse the interpretation of the plotting for the first leg of the exercise.

GLOSSARY OF NAVIGATIONAL TERMS

"Speak English," said the Eaglet, "I don't know the meaning of half those long words, and, what's more, I don't believe you do either."

—ALICE IN WONDERLAND.

- Abac**—is a device for obtaining the conversion angle to apply when plotting Great Circle bearings upon maps on Mercator's projection.
- Air Navigation**—is the art of conducting an aircraft from place to place, whether or not the ground is observed, by day or night. It consists of dead reckoning, supplemented by observations of terrestrial objects and Heavenly Bodies.
- Airspeed**—is the speed of the aircraft relative to the air undisturbed by its motion.
- Airspeed Indicator**—shows the speed of an aircraft through air of standard density.
- Allimeter**—is an aneroid barometer graduated in units of height.
- Altitude**—is the angle measured at the observer between a Heavenly Body and the horizontal.
- Astrograph**—is an instrument for plotting Star position lines upon a map on Mercator's projection at night.
- Axis of the Earth**—is that diameter about which the Earth rotates.
- Azimuth**—is the horizontal direction at an observer, in which a Heavenly Body lies at a particular moment. It is sometimes used in a wider sense to mean Bearing. (See "Bearing.")
- Beam**—is that direction on either side of an aircraft at right-angles to its heading.
- Bearing**—is the horizontal direction measured clockwise from North between the meridian at an observer and the line joining him to some point on the Earth's surface. As the meridian may be True, Magnetic or Compass, the bearing must be appropriately named. Bearings are always expressed in three-figure groups.
- Bearings are sometimes called "Azimuths."
- Bow**—is that sector on either side of an aircraft between ahead and abeam.
- Cardinal Points**—are the directions North, East, South, West.
- Centesimal**—describes the measurements of angles by the Metric System. A right-angle is divided into 100 "grades," each grade into 100 minutes, and each minute into 100 seconds.
- Coastal Refraction**—is the distortion of an Earth-bound wireless wave as it passes from land to sea, or vice versa.
- Cocked Hat**—is the intersection of three lines that do not meet at one point.
- Coefficients**—in the magnetic sense—are calculated quantities used in the analysis of compass deviation caused by various components.
- Compass**—is an instrument which serves to indicate directions.
- Compass Direction**—is a direction measured with reference to a particular compass needle which is more often than not displaced from the True meridian. Such a direction is named "C."
- Compass Error**—is the angle between a particular compass needle and the True meridian passing through its pivot, and comprises the algebraic sum of Variation and Deviation.
- Compass Rose**—is a circle divided into 360° from which directions may be measured.
- Compressibility**—refers to that property of air by which it can be compressed and which complicates the measurement of Airspeeds at great heights and high speeds.
- Constellation**—is a recognisable group of stars by means of which individual stars may be identified.
- Contour**—is a line drawn on a map joining all places of equal height above a certain datum level.
- Convergency**—is the inclination between True meridians on the Earth's surface. There is no convergency between meridians at the Equator; at the Poles the meridians converge at angles equal to the change of Longitude between them. The value of convergency is approximately :—

Ch. Longitude $\times$ sin Mean Latitude.

- Conversion Angle**—is the angle between a Great Circle bearing and a Rhumb line bearing. Its value is approximately half convergency.
- Couple**—Two equal forces acting in opposite directions on a body form a couple, which is expressed as the product of one force and the perpendicular distance between them.
- Course**—is the direction in which an aircraft is heading. Since the direction may be measured from the True, Magnetic or Compass meridian, the Course must be named accordingly T, M, or C.
- Critical Point**—is that position during a flight from which it is equally quick to proceed to the destination or return to the place of departure.
- Curve of Equal Bearing**—is a line from any place on which all True Great Circle bearings of a given point on the surface of the Earth are equal. It constitutes the position line obtained from D/F loop bearings.
- Datum**—refers to a direction, level or position from which angles, heights, depths, speeds or distances are conventionally measured.
- Dead Reckoning**—consists of calculating the Course, Track, Ground Speed and Position of an aircraft in flight from a knowledge of the probable Wind Velocity and the True Airspeed.
- Declination**—is the arc of a celestial meridian intercepted between a Heavenly Body and the celestial Equator. It corresponds to the latitude of that point on the Earth directly beneath the Heavenly Body.
- Deviation**—is the angle measured in the horizontal plane between the Magnetic meridian and the direction of a particular compass needle influenced by magnetic fields in addition to that of the Earth. It is named E (+) or W (−) according to whether the North-seeking Pole lies to the East or West of the Magnetic meridian. Its sign indicates how it is applied as a correction to compass readings to obtain Magnetic.
- Dip of the Sea Horizon**—is the angle of depression below the horizontal subtended by the sea horizon at an observer's eye. Its value depends on the height of eye above sea level.
- Directional Gyro**—is an air-driven gyroscope used by the Pilot for steering. It is more stable over short periods than a magnetic compass.
- Drift**—is the angle between the Course and Track of an aircraft. It is named "Starboard" or "Port" if the Track goes to the starboard or port of the Course.
- Equator**—is the Great Circle whose plane is at right-angles to the Earth's axis.
- First Point of Aries**—is a Datum point on the celestial Equator from which the Sidereal Hour Angles of stars is measured.
- Fix**—is a ground position of an aircraft determined by terrestrial or astronomical observations.
- Front**—is a change of air mass, and is characterised by a change of Wind, temperature, pressure and weather conditions.
- Gradient** (of map contours)—is a rate of rise or fall, usually expressed as a fraction. Thus 1/30 represents a gradient of one vertical unit in every thirty horizontal units.
- Graticule**—is the network formed on a map or globe by meridians (of Longitude) and parallels of Latitude.
- Great Circle**—is a circle on the surface of a sphere the plane of which passes through the centre of the sphere and divides it into two equal parts. The shortest distance between any two points on the surface of a sphere is the smaller arc of the Great Circle joining them.
- Grid**—is a rectangular network overprinted on certain maps by which positions can be reported.
- Ground Speed**—is the speed of an aircraft over the Earth.
- Hachuring**—is a method of representing relief upon a map by shading in short, disconnected lines drawn in the direction of steepest slopes.
- Height**—(i) The height of an aircraft is registered above mean sea level or above the level of a particular aerodrome by means of an altimeter.
(ii) The height of ground above datum level is expressed by spot heights or contours on maps.
- Horizontal Equivalent**—is the distance in plan between two adjacent contours.

Hour Angle—is the arc of the celestial Equator measured westwards from a given celestial meridian to that of a Heavenly Body. It corresponds to the change of Longitude westwards from a given meridian on the Earth to the meridian of that point directly beneath the Heavenly Body.

I.C.A.N. atmosphere—is a standard atmosphere laid down by the International Commission for Aerial Navigation for comparison of aircraft performances. It is used for the calibration of the Mk. XIV altimeter. The I.C.A.N. atmosphere has a pressure of 1013.2 mb. and a temperature of 15° C. at zero height, while temperature is assumed to decrease at 1.98° C./1,000 ft. up to 36,000 ft. above which the temperature is constant at -56.5° C.

The Mk. XIV altimeter measures the height interval in the I.C.A.N. atmosphere between the pressure at the level of the aircraft and the pressure read on the sub-scale.

For a note on the corrections necessary to the readings, see Chapter 1, paras. 64-69, and A.P.1931, Chapter IX.

Inertia—is the tendency of matter to resist a change of motion.

Intercept—is the difference in minutes of arc between the Observed Altitude and the Calculated Altitude of a Heavenly Body. It is named "Towards" if the former is greater, and "Away" if it is less than the latter.

Interception—is a tactical operation in which an aircraft meets another moving object with the least possible delay.

Isobar—is a line drawn on a map joining all points of equal atmospheric pressure when the pressure has been reduced to mean sea level equivalent.

Isoclinal—is a line drawn on a map joining all places having equal Magnetic Dip.

Isogonal—is a line drawn on a map between all places having equal Magnetic Variation.

Isothermal—defines a standard atmospheric condition as having a uniform temperature of 10° C. at all heights. Some altimeters are based on this assumption and register incorrect height when different atmospheric temperatures are experienced.

Knot—is the speed of one nautical mile an hour.

Latitude—(i) **Latitude** is the arc of the meridian of a place intercepted between the place and the Equator and is named "N" or "S" according to whether the place is North or South of the Equator.

(ii) **Parallel of Latitude** is a small circle, parallel to the Equator.

(iii) **Change of Latitude** is the arc of a meridian intercepted between the parallels of two places on the Earth and is named "N" or "S" according to the direction of the change.

Layer Tinting—is a method of showing relief on maps by colouring in different shades those parts which lie between different levels.

Longitude—(i) **Longitude** is the smaller arc of the Equator intercepted between the Prime meridian and the meridian of a place. It is named "E" or "W" according to whether the place is East or West of the Prime meridian.

(ii) **Change of Longitude** from one place to another is the *smaller* arc of the Equator intercepted between the meridians of the places. It is named "E" or "W" according to the direction of the change.

Lubber Line—is a Datum line indicating the fore-and-aft axis of the aircraft.

Magnetic Dip—is the angle of depression below the horizontal at an observer of the Earth's total magnetic force.

Magnetic Equator—is a line joining all points where the direction of the Earth's total magnetic force is horizontal and hence where Magnetic Dip is Zero.

Magnetic Field—is a disturbance of the æther set up round a magnet.

Magnetic Latitude—is defined by the horizontal magnetic force experienced at a place.

Magnetic Meridian—the direction of the axis of a freely-suspended magnetic needle influenced only by the Earth's magnetic field.

Magnetic Poles—are those two positions on the Earth where the Earth's total magnetic force is vertical and hence where Magnetic Dip is 90°.

- Meridian**—is a Semi Great Circle joining the Poles of the Earth. The other half of the Great Circle is called an "Anti-Meridian."
- Micro-Adjuster**—is a device for neutralising the magnetic fields causing Deviations in a magnetic compass.
- Millibar**—is a unit of atmospheric pressure used by Meteorologists. It is equal to 1,000 dynes per square centimetre.
- Nautical Mile**—is the average length of 1 minute of Latitude, and is generally accepted as 6,080 feet.
- Night Effect**—the distortion of wireless waves reflected by the Heaviside layer, causes incorrect D/F bearings to be obtained by loop aerials, especially at sunrise and sunset.
- Noon**—is the moment when the Sun is on an observer's meridian.
- Orbit**—is the path of a satellite revolving round a Heavenly Body.
- Orientation**—consists of turning an instrument or map until a Datum point or meridian is aligned with a True meridian on the Earth.
- Origin**—denotes in this Manual the point on the Earth from which a position line is obtained.
- Parallax in Altitude**—is the angle by which observed altitudes of the Moon must be increased to compensate for the under-measurement due to the proximity of the Moon.
- Pin-Point**—is the ground position of an aircraft obtained by direct observation of the ground.
- Planisphere**—is an instrument facilitating star identification.
- POLARIS**—is the name of the star almost directly above the North Pole.
- Poles**—of the Earth are the extremities of its axis of rotation.
- Port**—is the left side of the aircraft.
- Position Error**—is the error in the reading of an Airspeed Indicator caused by the imperfect positioning of the Pitot Head which thus gives incorrect indications of static atmospheric pressure.
- Position Line**—is a line obtained from observations of a terrestrial or celestial origin. The observer is known to be somewhere upon the line at the time of observation.
- Precession**—is the movement of the axle of a gyroscope which occurs when a couple is applied to it. The axle moves as if the couple, before being applied, had been turned through 90° in the same direction as the spin.
- Projection**—is an orderly system of representing the surface of the Earth upon a plane surface.
- Q Correction**—is applied to observed altitudes of POLARIS to compensate for the latter's not being directly overhead at the North Pole at the moment of observation.
- Quadrantal Errors**—are the errors to which an aircraft D/F loop is subject. They have maximum values at the quadrantal relative bearings.
- Quadrantal Points**—are North-East, South-East, South-West, North-West.
- Quarter**—is that sector on either side of an aircraft between abeam and astern.
- Radius of Action**—is the maximum distance along a Track which can be covered by an aircraft before it must turn for its base.
- Rate of Climb Indicator**—shows the rate of ascent or descent by gauging the intensity of short-period changes of atmospheric pressure.
- Rate of Turn Indicator**—gauges the rate of turn by the precessional torque applied to a horizontally-mounted gyroscope. There are four arbitrary rates of turn.
- Refraction**—is the distortion of the direction of a ray of light or wireless wave.
- Relative Bearing**—is a direction measured clockwise from the heading of an aircraft from 0° to 360°. Added to the True Course it becomes a True bearing (—360° if necessary). In nautical parlance, a relative bearing is named "Red" or "Green" according to whether the bearing, measured from 0° to 180° of the heading, is to Port or Starboard, respectively.
- Representative Fraction**—is the ratio between a length on a map and the distance it represents on the Earth (expressed in the same units).
- Rhumb Line**—is a curved line on the Earth's surface cutting all meridians at the same angle.

- Route Forecast*—is a statement of weather likely to be encountered when flying from one place to another.
- Run*—is the direction and distance travelled by an aircraft over the ground during a certain time.
- Semi-Diameter*—is the radius of the Sun or Moon which must be applied to observed altitudes when the Upper (—) or Lower (+) limb of either is measured against the sea horizon by a marine sextant.
- Sexagesimal*—defines that system of measurement based on the number "60."
- Sextant*—is an instrument for measuring the altitude of Heavenly Bodies.
- Sidereal*—pertaining to the Stars, stellar.
- Small Circle*—is a circle on the surface of a sphere, the plane of which does not pass through the centre of the sphere.
- Spherical Triangle*—is a triangle the sides of which are arcs of Great Circles.
- Spot Height*—is a record on a map of the exact height of a particular place above datum level.
- Starboard*—is the right-hand side of an aircraft.
- Sub-Stellar Point*—is that Point on the Earth directly beneath a star. In this Manual it also refers to points beneath all Heavenly Bodies.
- Synoptic Chart*—or Weather Map—shows the pressure distribution, temperatures, Winds, clouds, weather conditions and tendencies at a given moment of observation. It provides data for weather forecasting.
- Time*—is measured by the rotation of the Earth relative to the Sun, Moon, Stars or an imaginary body called the Mean Sun. These define apparent solar, lunar, sidereal or mean time respectively.
- Track*—is the direction of the path of an aircraft over the ground. The "Required Track" is the direction which an aircraft is intended to follow. The "Track made good" is the direction of the path actually traced over the ground.
- Twilight*—is that period between absolute darkness and the rising or setting of the Sun.
- Variation*—is the horizontal angle between the direction of True North and Magnetic North at a place. It is named E (+) or W (—) according to whether the direction of Magnetic North is to the East or West of True North. Its sign indicates how it is applied as a correction to Magnetic directions to obtain True directions.
- Vertical Interval*—is the difference in level between two adjacent contours.
- Visibility*—is a measure of atmospheric clarity, defined by the maximum distance an object can be seen and recognised distinctly. The size of the object, as well as atmospheric clarity, is therefore a factor in visibility.
- Wander*—is the acceleration caused by a change of direction in flight.
- Weather Forecast*—is a prediction of weather conditions likely to be experienced over a wide area.
- Weather Report*—is a statement of the weather actually being experienced at some place.
- Z Correction*—is the allowance made for error in bubble sextant observations due to Wander.
- Zenith*—is the point in the heavens directly above an observer.

APPENDIX I.

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Signed Navigator.



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Signed.

Ch. S. Shawbury. 17%.

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8

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THE SICKLE

27 Alpher
30 Denebola

SQUARE OF PEGASUS

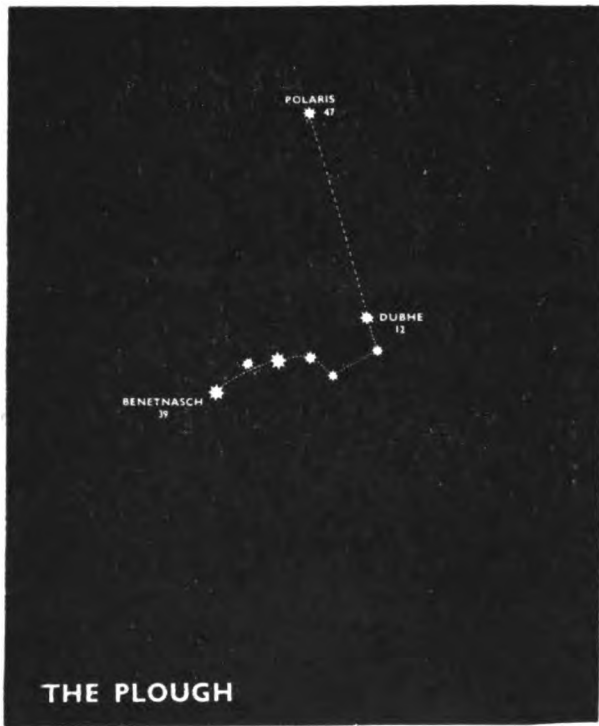
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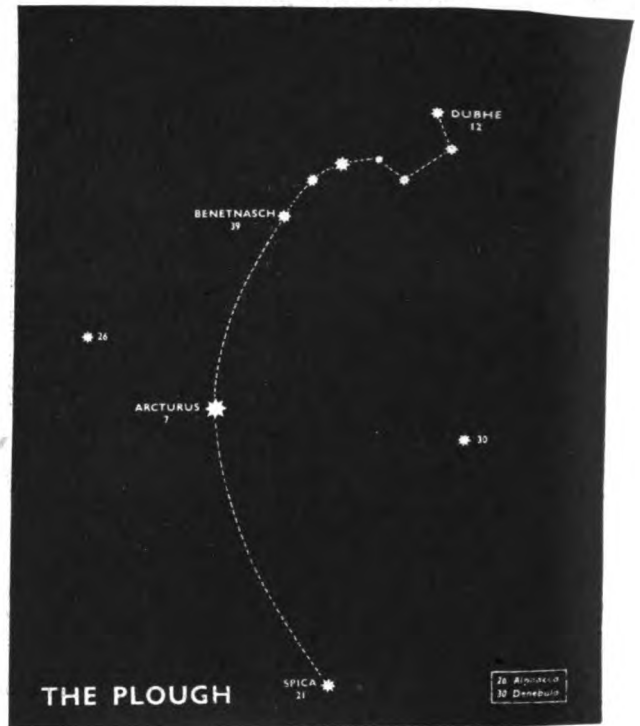
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THE R.A.F. STAR CHARTS.

R.A.F. STAR CHART No. 1



R.A.F. STAR CHART No. 2



R.A.F. STAR CHART No. 3



R.A.F. STAR CHART No. 4



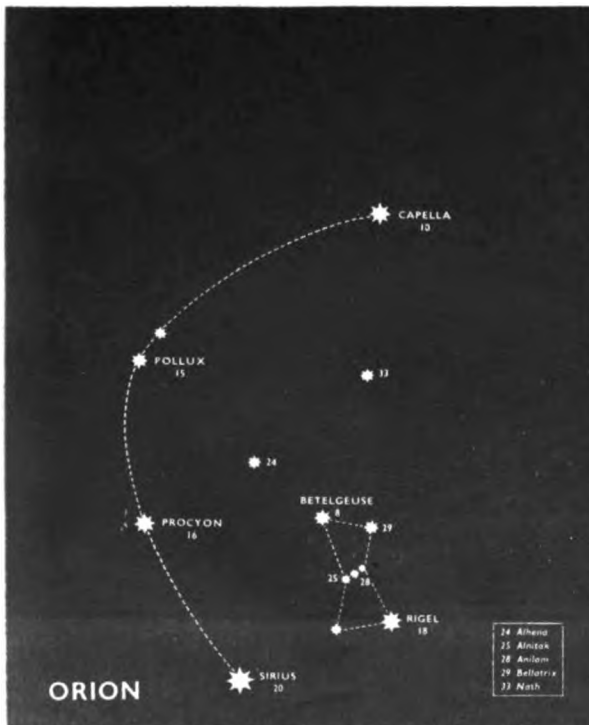
R.A.F. STAR CHART No. 5



R.A.F. STAR CHART No. 6



R.A.F. STAR CHART No. 7



R.A.F. STAR CHART No. 8



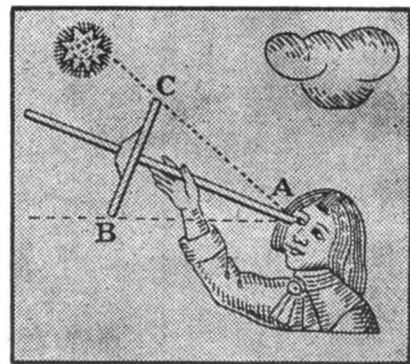
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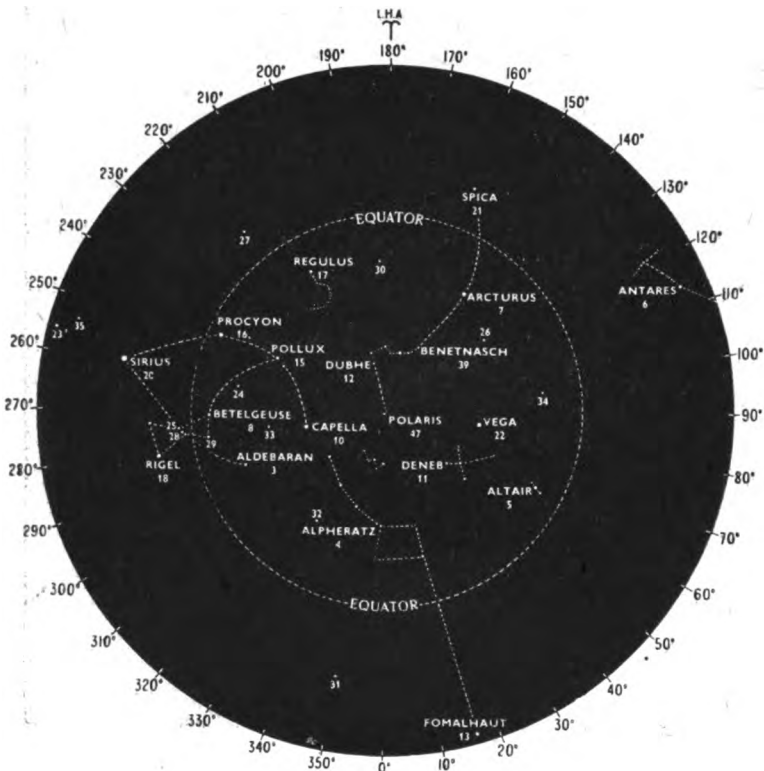


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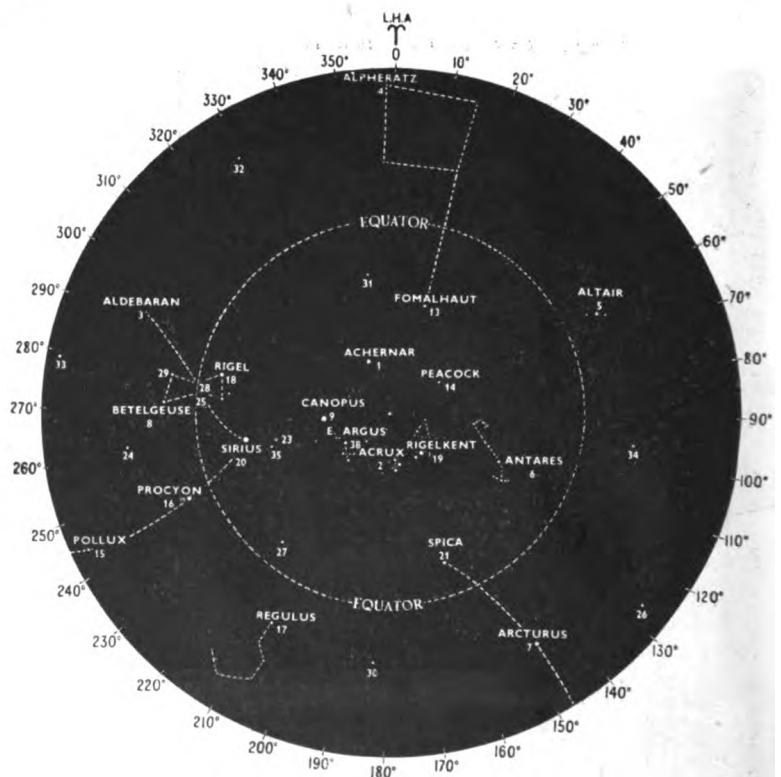
MAN IS NOT LOST

R.A.F. STAR CHART No. 12
Northern Hemisphere



- 23 Adara
 24 Alhena
 25 Alnitak
 26 Alphacca
 27 Alphard
 28 Anilam
 29 Bellatrix
 30 Denebola
 31 Diphda
 32 Hamal
 33 Nath
 34 Ras Alhague
 35 Wezen

R.A.F. STAR CHART No. 13
Southern Hemisphere



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